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Friction Coefficients of Brake Linings

Mechanical Engineering

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FRICTION COEFFICIENTS OF BRAKE LININGS

BY

DONALD ERSKINE BUYERS

THESIS

FOR THE

DEGREE OF BACHELOR OF SCIENCE

IN

MECHANICAL ENGINEERING

COLLEGE OF ENGINEERING

UNIVERSITY OF ILLINOIS

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

Donald Erskine Buyers

ENTITLED Friction Coefficients of Brake Linings

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in

Mechanical Engineering

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FRICTION COEFFICIENTS

OF

BRAKE LININGS

INTRODUCTION

The object of this thesis is to investigate the coefficient of friction of a number of brake linings now on the market with a view to determine their applicability to Prony brake work. The writer undertook this work through a natural inclination toward experimental work and because of the lack of much definite information on the subject. It was expected that tests to determine the coefficient of friction of each material with variations of pressure on the surface of contact and variations of the speed of the surface of contact, and also endurance tests be run. Owing to lack of apparatus it was necessary to build an almost entirely new outfit with which to work. This construction consumed from twelve to fifteen hours a week for twelve weeks or practically two-thirds of the total time in which the thesis was supposed to be completed. Consequently the writer was unable to complete all of the tests that he had planned to make but hopes that a good foundation has been laid for a more exhaustive and complete investigation along these lines at a later date.

Before any work was begun, a circular letter was sent out

to about eighteen manufacturers, asking for samples of their product for this purpose. These letters stated that the results obtained from these tests would be available for the use of the manufacturer. These letters, on the whole, met with a ready and cheerful response. The samples received were nearly all fibrous in structure, preparations of asbestos predominating although compositions of rubber and some cotton coated with or containing tarry preparations were received. One metal sample, one hair sample, and one cork insert sample were received. In the latter case a pair of brake blocks were sent to the manufacturer and the inserts made in the factory.

Practically all of the construction work on the apparatus was done by the writer in the shops of the University. Through the courtesy of Mr. B. W. Benedict, Director of the University Shops, the writer was saved considerable manual labor in the making of patterns, castings, and one or two small forgings. All of the test work was done in the Mechanical Engineering Laboratory of the University.

CHAPTER I.

Description of Apparatus

1. After investigating the suitability of the various machines and apparatus in the Mechanical Engineering Laboratory, the writer concluded that the best way to proceed was to build a brake stand and obtain power by means of a belt to the 10" x 10" Ideal high speed engine. Two 8" x 8" timbers that were joined together by cross pieces were bolted to the floor, and upon these were mounted a pair of shaft hangers with babbitted bearings supporting a cold rolled shaft. The shaft was so badly rusted that it was necessary to turn it down to a smaller diameter for the entire length, which, of course, made it necessary to re-babbitt the bearings. A twenty-six inch pulley having a bore that was much too large was fitted with a cast iron bushing and mounted securely upon the shaft between the bearings. To one end of this shaft was keyed a heavy cast iron spider, upon which was fastened a brake sheave taken from one of the gas engines in the laboratory. An elevation sketch of this lay-out is shown in Figure 1, page 4. The engine is shown at F. The drive pulley on the brake stand is shown at A with the brake sheave at B. The hangers, D, are bolted to the timbers, E, and support the shaft upon which the pulley and sheave are mounted. The brake, C, partially encircles the sheave with the outer end resting on the platform scales, G. The plan view is shown in

PLATE 1.

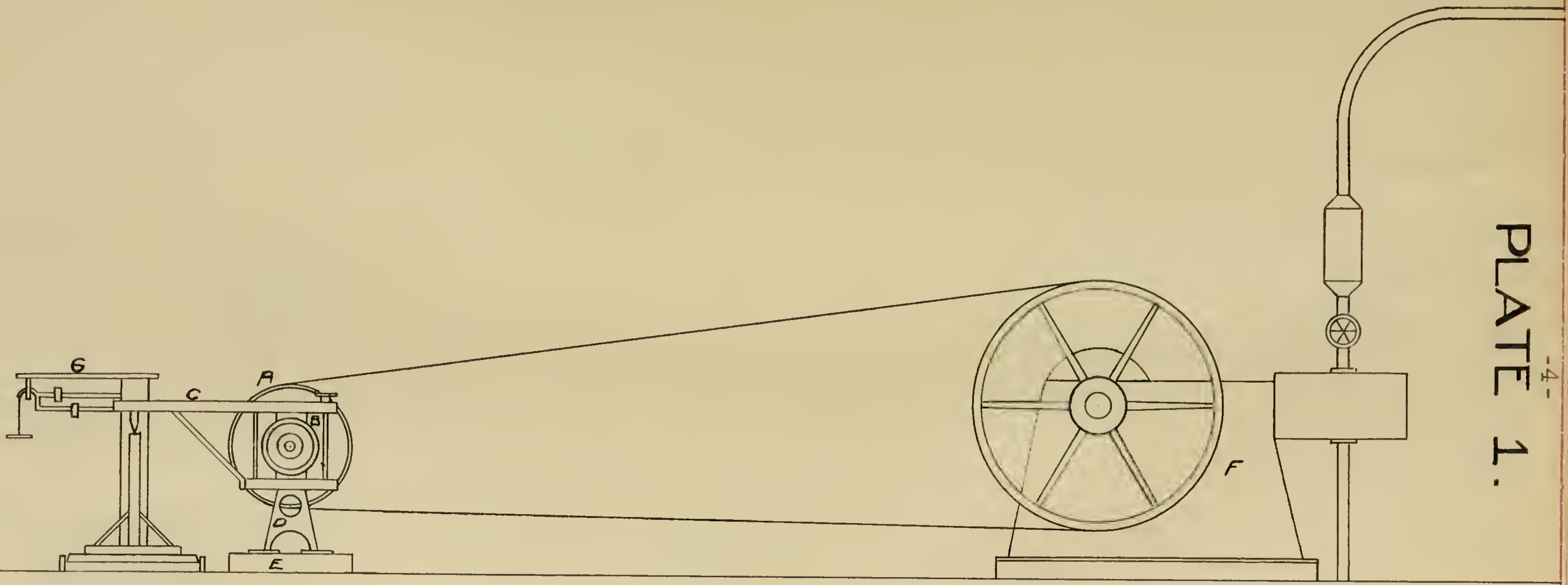


FIG. 1.

DIAGRAMMATIC SKETCH OF APPARATUS – ELEVATION

PLATE 2.

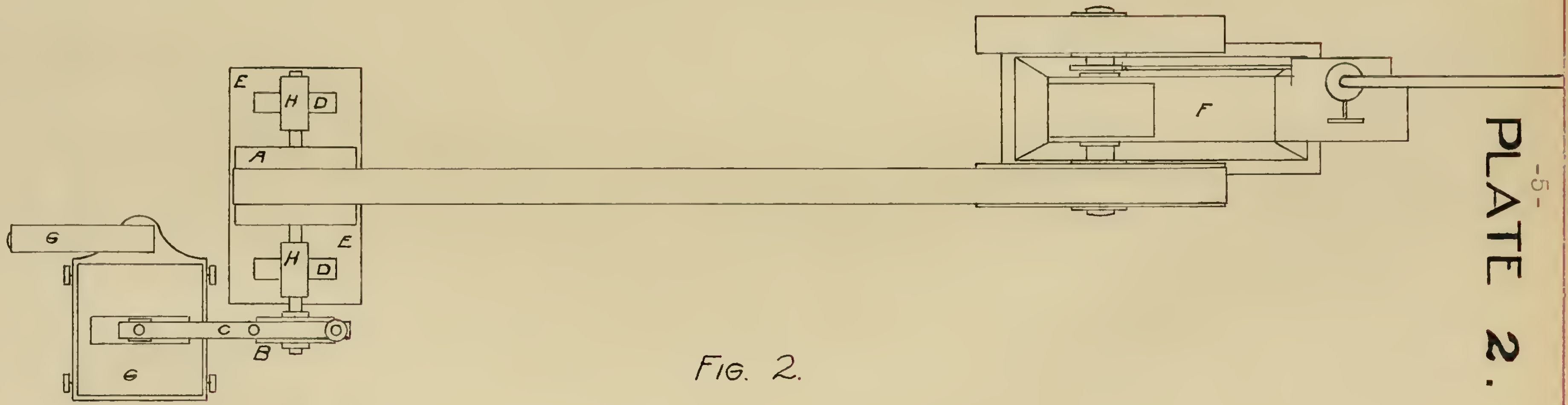


FIG. 2.

DIAGRAMMATIC SKETCH OF APPARATUS — PLAN

Figure 2, page 5. The same letters for the various parts apply to both figures except that the additional letter H is used to designate the bearings which do not show in Figure 1.

Having assembled the brake stand, the next thing to be done was to make a brake. This was to be some form of Prony brake. The object of this brake was to measure the tangential force and the normal pressure at the surface of contact between the sheave and the brake. The tangential force could be readily obtained by letting the end of the brake rest on an ordinary platform scales and by putting enough weight on the scales to just balance the force due to the brake. The force at the rim of the pulley would then be in the proportion to the weight on the scales as the inverse ratio of their distances from the center of rotation. The problem then was to measure the pressure of the brake blocks upon the pulley. It was decided that the simplest way to accomplish this would be to put a calibrated spring on the bolt holding the brake blocks together, and the compression of this spring would be a measure of the force holding the two blocks together. This spring is shown at G in Figure 3, page 7. A hand wheel, F, was then divided on the circumference into divisions that read to one-thousandths of an inch thus affording a means of measuring accurately the compression of the spring. Before beginning the tests this spring was taken to the Laboratory of Theoretical and Applied Mechanics and calibrated on one of the testing machines. This calibration curve is shown on page 17.

To facilitate making measurements between the action lines of the various forces, all points of application of pressure were made in the form of knife edges as shown in Figure 3 at D for the

PLATE 3.

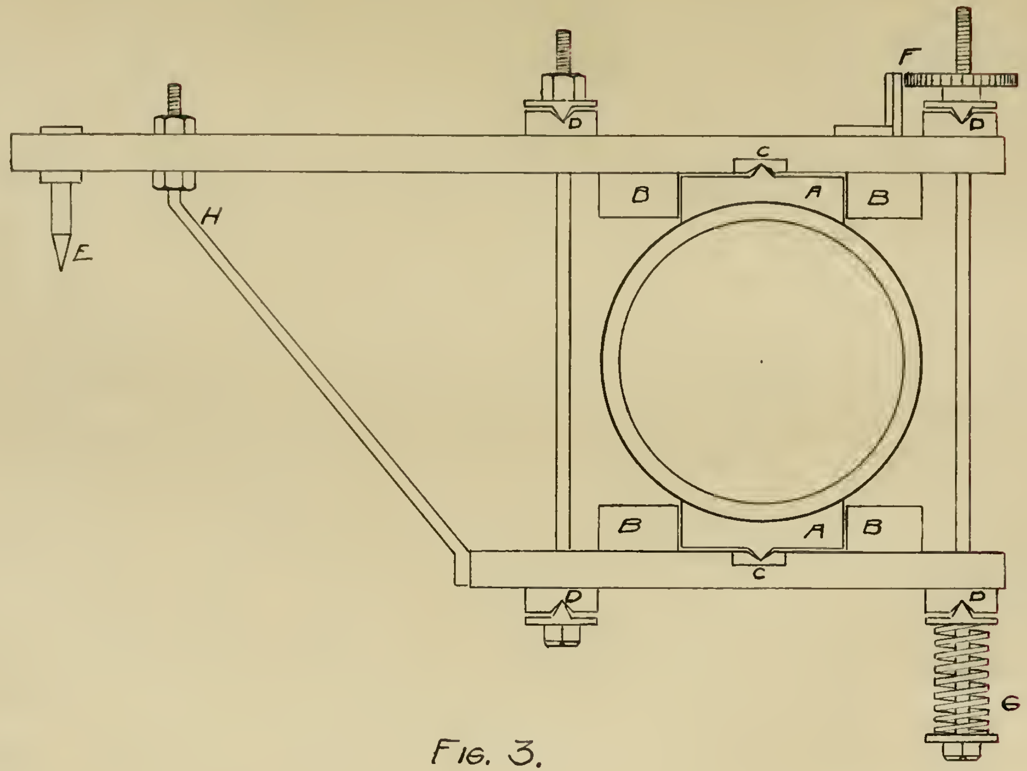


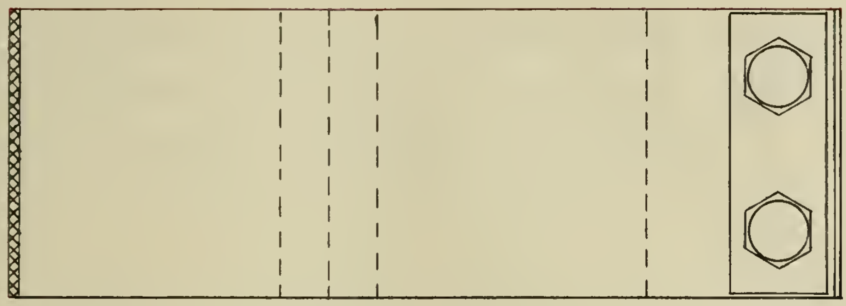
FIG. 3.

SKETCH OF BRAKE FOR TESTING LININGS

bolts and at C for the blocks. The point E was at the end of a round bar of iron sharpened to a point. The knife edges at D were made of wrought iron plates and the bearing plates were screwed fast to the wooden frame of the brake. At C the bearing plates were set into the wooden frame of the brake and also fastened with screws. The blocks that carried the knife edges at C were made of cast iron and were removable. An enlarged sketch of one of these blocks is shown in Figures 4 and 5 on page 9.

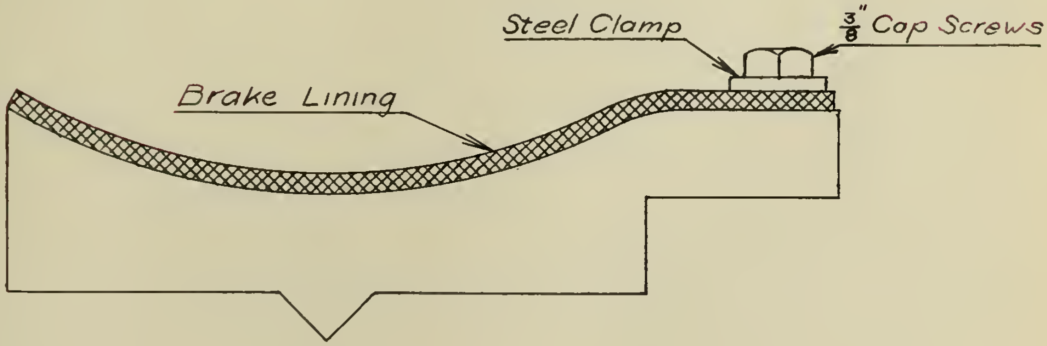
The method of applying the linings to these blocks is shown in the two figures mentioned above. The linings were laid flat on the curved side with the end turned over the extention on the end of the shoe and is shown by the cross section in Figure 5. The end of the lining was held fast to the extention on the shoe by means of a hardened steel plate or clamp which was held by two cap screws that screwed into the extention. These shoes are shown at A in Figure 3, page 7. Wooden blocks, B, were fastened at each end of the shoes to prevent the shoes from travelling around with the wheel when the pressure was released. In order to keep the lower part of the brake from swinging a brace, H, was put on. The flat end of this brace was screwed onto the lower part of the brake and at the upper end a long thread was cut. Two nuts were put on this thread one above and one below the frame of the brake in order to clamp the brace rigidly. By moving both nuts up or down the distance between the two parts of the brake could be decreased or increased to suit the thickness of the lining that was placed between the shoes and the wheel. At F a piece of iron bent at an angle of 90° and sharpened on the edge next to the hand wheel was screwed fast to the brake and served as an index to facilitate

PLATE 4.



Plan

Fig. 4.



Elevation

Fig. 5.

Cast Iron Brake Shoe

reading the divisions on the hand wheel.

The brake sheave was thirteen and three-eighths inches in diameter and the distance from the point E to the center of the sheave was twenty-nine inches. The distance between the knife edges D was sixteen and one-half inches and from C to D eight and one-quarter inches.

This apparatus at best is rather crude and the results obtained from its use should not be considered extremely accurate although they are perhaps reasonably approximate.

Theory Involved

2. The theory involved in the apparatus just described is as follows:

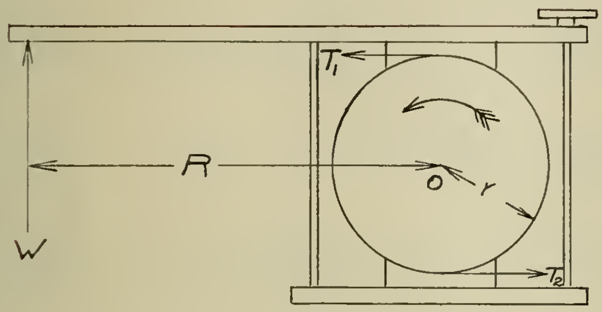


FIG. 6.

In Figure 6 when the wheel is rotated in the direction shown by the arrow, we have the brake acted upon by the three forces W, T_1, and T_2 where T_1 and T_2 are forces due to friction between the wheel and the blocks. Assuming the brake to be in equilibrium the moments of these three forces about a point O must equal zero. If r is the radius of the brake sheave, R is the perpendicular distance from O to the action line of W, and the rotation shown is considered positive, we have

$$T_1r + T_2r - WR = 0$$

$$\text{or} \quad (T_1 + T_2)r = WR \quad \text{---------------------------(1)}$$

If T is the total tangential force due to friction then $T = T_1 + T_2$ and we have

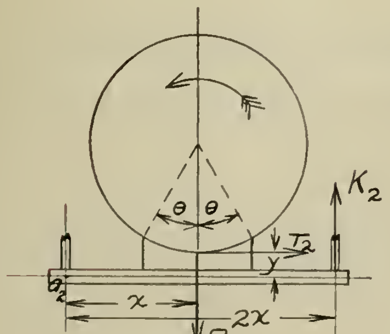


FIG. 7.

$$Tr = WR \quad \text{------- (2)}$$

$$\text{or} \quad T = \frac{WR}{r} \quad \text{-------- (3)}$$

If we now consider but one-half of

the brake as shown in Figure 7 we have a form of brake similar to that shown in Figure 34 on page 61 of Part I of the Notes on Mechanics of Machinery by Professor G. A. Goodenough and Assistant Professor O. A. Leutwiler. The point a_2 is fixed by being rigidly attached to the other half of the brake. There are then four forces acting upon the brake namely K_2, T_2, P_2 and that applied at the point a_2. For this condition then equation 125 on page 61 of the text referred to above is applicable and we have

$$T_2 = 2\mu P_2 \frac{\sin\theta}{\theta + \sin\theta\cos\theta} \text{ -------------- } (4)$$

where μ is the coefficient of friction of sliding between the block and the sheave. In the brake used in these tests the angle θ was made 30° and by looking on page 62 of the same text we find that for $\theta = 30°$ the value of the fraction $\left(\frac{\sin\theta}{\theta + \sin\theta\cos\theta}\right)$ is 0.523

Substituting this value in equation (4) we have,

$$T_2 = 1.046\mu P_2 \text{ ----------------------- } (5)$$

and $$T_1 = 1.046\mu P_1 \text{ ----------------------- } (6)$$

Then by adding equations (5) and (6) we get

$$(T_1 + T_2) = 1.046\mu(P_1 + P_2) \text{ ------------- } (7)$$

Then by taking moments about O in Figure 6 the moment M_1 of T_1 is T_1r and the moment M_2 of T_2 is T_2r. Then if M is the total moment we have

$$M = M_1 + M_2 = r(T_1 + T_2)$$

Then since $(T_1 + T_2)$ is equal to T we have

$$T = \frac{M}{r} = T_1 + T_2 \quad \text{------------------------} \quad (8)$$

Substituting in equation(7)we have

$$T = 1.046\mu(P_1 + P_2) \quad \text{-------------------} \quad (9)$$

$$\text{or} \quad \mu = 0.956 \frac{T}{P_1 + P_2} \quad \text{------------------------} (10)$$

Then taking moments about a_2 in Figure 7 we have

$$2K_2x - P_2x - T_2y = 0 \quad \text{------------------} \quad (11)$$

and for the upper brake arm

$$2K_1x - P_1x + T_1y = 0 \quad \text{------------------} \quad (12)$$

Then making the most logical assumption that T_1 is equal to T_2 and letting K_1 equal K_2 equal K we get by adding equations (11) and (12)

$$4Kx - (P_2 + P_1)x = 0$$

$$\text{or} \quad P_2 + P_1 = 4K \quad \text{----------------------------} (13)$$

Therefore, to find the value of μ we must find the value of T and $(P_1 + P_2)$ in equation (10). The value of T is readily calculated from equation (3) and $(P_1 + P_2)$ from equation (13) after W in equation (3) and K in equation (13) have been determined experimentally.

It will be noted that for the upper part of the brake the force T_1 is helping K_1 and for the lower part T_2 is opposing K_2, therefore, K_2 must be greater than K_1 and hence P_2 will be greater than P_1. Then the coefficient of friction will be different for

the two blocks and the value found in this series of tests will be an average of the two real coefficients.

If the brake in Figure 6 had a weight, W, at the end and was rotated instead of the weight, W, holding the brake stationary, we would have the same amount of work done as that absorbed by friction. The work done per minute would be the weight, W, times the distance through which it moved in a minute or $2\pi RN$ where R is the distance from the center of rotation as shown in the figure in feet, and N is the number of revolutions per minute made by the brake. Since one horsepower is equal to 33,000 foot pounds of work per minute, the horsepower of the brake would then be

$$H.P. = \frac{2\pi RNW}{33000} \quad \text{-------------------------} \quad (14)$$

Since in this brake R was 2.419 feet and substituting the value of 3.14 for π we have

$$H.P. = \frac{2 \times 3.14 \times 2.419 \times N \times W}{33000}$$

$$= 0.00046NW \quad \text{---------------------} \quad (15)$$

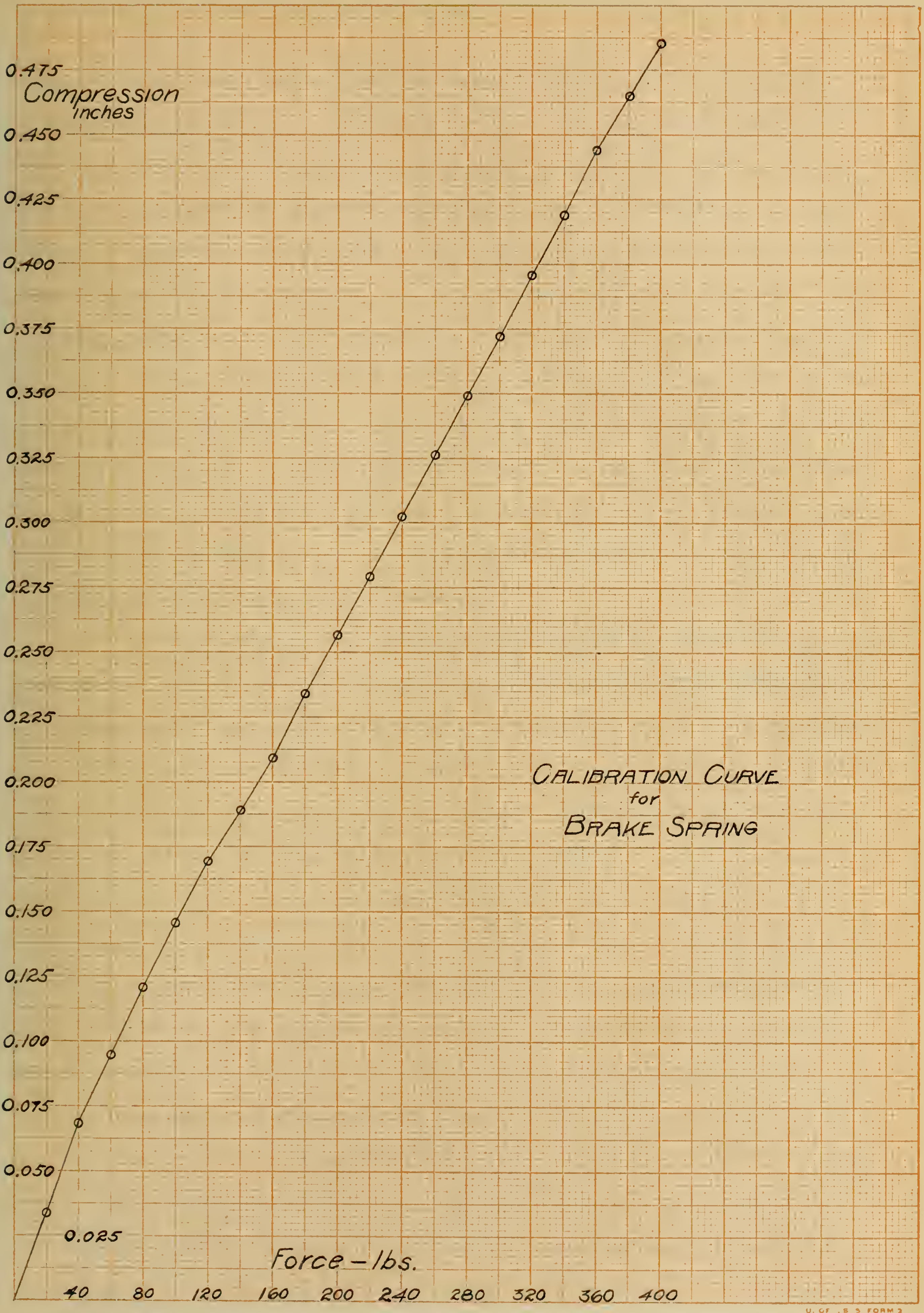
CHAPTER II.

Method of Conducting Tests.

1. After the apparatus described in Chapter I had been assembled and connected to the source of power a sample of lining was selected. It was applied to the brake shoes and clamped fast. These shoes were then placed on the brake and the two bolts screwed up until the lining just touched the brake wheel and the brace then adjusted. This brace and the bolt not carrying the hand wheel were not changed thereafter during the test. The pressure of the brake on the scales was found by adjusting the weight on the scales until the beam was balanced. This weight was found to be thirty-five pounds and was kept on the scales all of the time by wedging the rider on the upper bar of the beam. The rider on the lower bar of the beam was then used to measure the applied load. This rider was then placed at about thirty pounds and the engine was started. A small stream of water was turned on to the inside of the flanged rim of the brake wheel to keep it from getting excessively hot. The hand wheel was then screwed up until the thirty pounds was balanced and the brake operated for about five minutes at this load. This was done to warm up the lining and make it conform to the surface of the shoe as some of the linings were rather stiff and not easily bent to the curve by hand. This also removed any uneveness of the surface and formed a good uniform friction surface.

The rider was then placed at zero and the hand wheel unscrewed until the pressure was released and the brake just balanced tare. The position of the hand wheel was then read. The rider was then placed at ten pounds and the hand wheel turned up rapidly until the scales were again in balance and the number of divisions through which the hand wheel had been turned was noted. This number of divisions gave directly in one-thousandths of an inch the amount of compression of the calibrated spring. When this spring was calibrated in the testing machine the data obtained from the test was plotted on the coordinate paper on page 17. The values of the compression force in pounds were laid off on the axis of abscissa and the values of the amount of compression in inches were laid off on the axis of ordinate. The points given by the data were then located with reference to these axes. These points were then connected by straight lines between the points making one long curve. When the compression of the spring was read on the hand wheel the point on this curve was was located by going horizontally from the ordinate axis until the curve was reached. From this point by going directly downward to the axis of abscissa the force which caused the compression could be directly read on this axis. This tnen was the value K that we wanted to find in equation (13) in the discussion of the theory.

When a reading had been taken the brake was again released and the rider brought back to zero and the position of the hand wheel again noted as the zero position for the next reading. This was necessary for, unless the brake was released immediately upon taking a reading the lining would often wear off from one-half to two-thousandths of an inch and to assume that the position of the hand

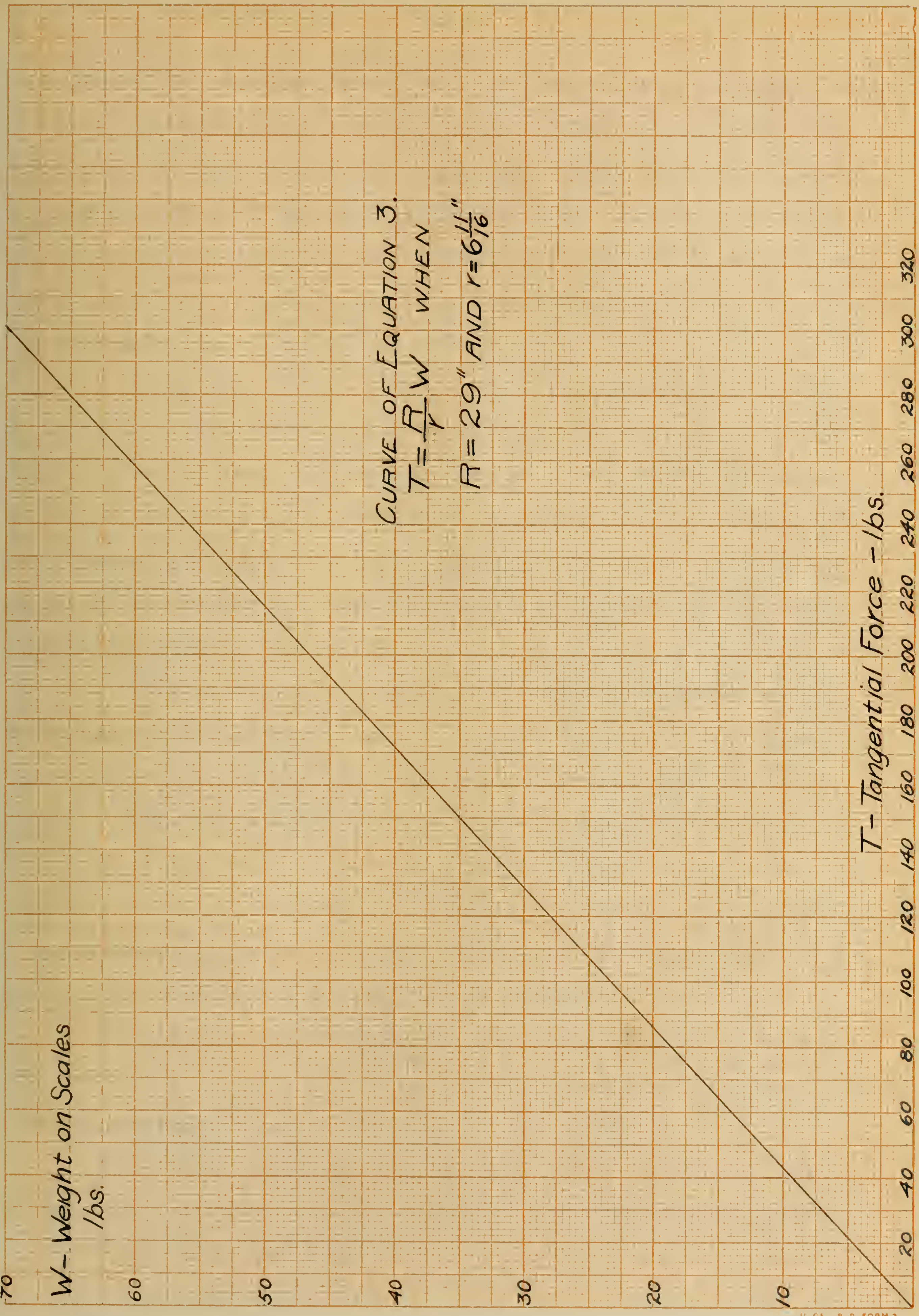

Compression inches
0.475
0.450
0.425
0.400
0.375
0.350
0.325
0.300
0.275
0.250
0.225
0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
Force – lbs.
40
80
120
160
200
240
280
320
360
400
CALIBRATION CURVE for BRAKE SPRING

wheel was the same for all of the zero readings, would introduce errors in the results. Sometimes as much as two-hundredths of an inch would be worn off before the completion of the tests.

The loads were increased by ten pound increments on the scales, beginning at ten pounds and going up to forty, fifty, or even seventy pounds according as the linings were able to stand it. Care was taken not to get excessive pressures thus causing too much heating. When a maximum had been reached the load was then shifted back five pounds and then reduced by ten pound increments until five pounds was reached. This method served as a check on the readings, the decreasing loads checking the increasing loads. It was thought that this would also reduce to a minimum the effect of increase of temperature with increasing pressures.

To save time in calculating the tangential force T for every load on the scales, two values of W in equation (3) were assumed and the values of T for those two points calculated. Since this equation is of the first degree it must represent a straight line hence, a straight line connecting the two points referred to above would be the graphical representation of the equation. This curve is shown on page 19. The ordinates represent values of W, and the abscissae, values of T. For any value of W the corresponding value of T will be found by running from the ordinate axis horizontally to the curve and then dropping vertically downward to the axis of abscissa where the value of T will be read directly in pounds.

Values of W were recorded in column (1) of the data sheets and the corresponding values of T as read from this curve, in column (2). The compression of the spring was recorded in column (3). The corresponding value as read from the calibration curve was K



CURVE OF EQUATION 3.

$T = \frac{R}{r} W$ WHEN

$R = 29''$ AND $r = 6\frac{11}{16}''$

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in equation (13) and when substituted in that equation gave the value of $(P_1 + P_2)$ which value was recorded in column (4). Column (2) and column (4) then contained the unknown values of T and $(P_1 + P_2)$ in equation (10). Then by substituting these values in equation (10) we obtained the values of μ which were recorded in column (5). Curves were then plotted with the values in column (4) as abscissae and the values in column (5) as ordinates.

During the various tests average revolutions per minute of the sheave were taken with a speedometer for each value of the weight on the scales. The weight on the scales was recorded in column (1) of Table I on page 46 and the values of the revolutions per minute, in column (2). The horsepower for each value of the weight on the scales was then calculated by formula (15) and the results recorded in column (3).

Table II was then made up of a series of columns headed with these values of horsepower. In each column the corresponding value from column (5) of the data sheets for each sample were recorded. This table then gave the values of the coefficient of friction for each sample with the various values of horsepower. From this table a curve was then drawn for each sample with the values of horsepower plotted on the axis of abscissa and the values of the coefficient of friction on the axis of ordinate.

The curves representing the results exhibited in columns (4) and (5) on the data sheets, show the variation of the coefficient of friction with change of pressure on the blocks.

The curves plotted from the data given in Table II represents the relation existing between the coefficient of friction and the horsepower absorbed.

Description of Brake Linings.

2. When these samples were asked for it was with the understanding that no manufacturer's name should appear in any published form of the results of these tests. We have, therefore, used letters to designate the different manufacturers. It will be noted that manufacturer A sent four samples, B one sample, C one sample, D three samples, F, H, and J each one sample, and E, I, and K two samples. Two other manufacturers each sent one sample but owing to several difficulties and lack of time these were not tested.

Sample A-1 was a mixture of asbestos and fine brass wire coated with a black substance and was white inside. This sample was quite flexible.

Sample A-2 was a combination of cotton and hair coated with a red preparation. It was not very flexible. The surface was very dry.

Sample A-3 was a stitched cotton fibre with a black binder, the surface was dull black and soiled the fingers when touched. It was not very flexible and when heated the black substance oozed out in a sticky mass on the surface and gave off an odor like belt dressing.

Sample A-4 was similar to A-3 except that it was red and was drier on the surface. The material was solid cotton folded and stitched. It was fairly flexible.

Sample B was a white asbestos and brass wire combination.

The surface was very powdery. This sample was rather stiff.

Sample C was a combination of asbestos and brass wire. It was somewhat flexible and had a black smutty surface.

Sample D-Grade A was a soft, very flexible, rather coarse woven, light weight combination of asbestos and brass wire.

Sample D-Grade AA was very much like grade A except that it was not so flexible and was a little finer woven and heavier.

Sample D-Grade AAA was similar to grades A and AA except that it was not so smutty and was very stiff and heavy.

Sample E-4 was a combination of asbestos and brass wire. It was very stiff with a black smutty surface. This sample was recommended by the manufacturer for use as a brake lining.

Sample E-7 was very much like E-4 except that it was lighter and more of a brown shade with a rougher and drier surface. This sample was recommended for use in friction clutches.

Sample F was a combination of rubber, asbestos, and very fine brass wire folded and stitched and had a very smooth rubbery surface.

Sample H was a combination of cotton, asbestos, and fine brass wire coated with a black preparation and having a glossy surface. It was not very flexible and had a slight tarry odor.

Sample I-1 was a mixture of rubber, asbestos, and wire folded and stitched. It was very stiff and had a slick, rubbery surface.

Sample I-2 was a combination of asbestos and brass wire with a smutty surface and was very stiff.

Sample J was a pair of cast iron brake shoes fitted with cork inserts. In making the inserts the manufacturer pared the

the cork down practically flush with the surface of the iron so that when the shoes were applied to the wheel parts of the cast iron touched the wheel due to irregularities in the surface.

Sample K-1 was a combination of cotton or asbestos and fine brass wire coated with a black preparation. It was somewhat flexible and had a smutty surface.

Sample K-2 was a preparation of asbestos and rubber containing fine brass wire folded and stitched. It was not very flexible and had a smooth rubbery surface.

CHAPTER III.

Discussion.

1. These tests as far as they were carried on gave fairly satisfactory results. In addition to these tests it was hoped that endurance tests could be made, but due to lack of time this had to be abandoned.

The materials tested may be classed in three groups as follows: (1) Those made of asbestos and rubber; (2) those made of cotton and wire; (3) those made of asbestos and wire.

The following samples compose group (1); C, F, I-1, and K-2. Those in the second group are the samples marked A-3, A-4, and K-1 while the third group consists of the following:- A-1, B, D-A, D-AA, D-AAA, E-4, F-7, H, and I-2. The sample marked A-2 was a combination of cotton and hair, and that designated as J was a cast iron shoe with cork inserts.

The materials of the first group formed very smooth surfaces when run. Those of the second group had a tendency to heat quickly and the black binder became somewhat soft; however, when they cooled off again the surface was very hard and glazed. Those of the third class seemed affected very little by the heat and quickly formed hard surfaces that remained unchanged throughout the tests.

No very great importance can be placed upon this classifi-

cation when studying the results because it was made merely by inspection and with no knowledge of the real constituents.

It will be noted that the two sets of curves as plotted from the data sheets and Table II are similar. The curve in each set for the same sample having approximately the same shape. The ordinates are exactly the same but the abscissae are not.

It will be noted also that the general tendency is for the coefficient of friction to decrease with an increase of pressure. In most cases the decrease is more rapid at the lower pressures and several samples show a tendency to become nearly constant at higher pressures. Sample A-2 was the only one for which the coefficient of friction did not decrease with an increase of pressure. It rose rapidly at the lower pressures but also exhibited a tendency to become fairly constant at the higher pressures. Samples A-3 and D-AA showed a marked increase at lower pressures and a rapid decrease at higher pressures. The writer was unable to determine the cause of this.

Conclusions.

2. Due to the incomplete series of tests performed on these various samples it is impossible to draw up any conclusions as to which sample is best fitted for Prony brake work. In these tests only one of the running conditions has been varied and furthermore each test was run for a comparatively short time. No doubt it would be best to have a lining whose coefficient of friction remained nearly constant, for in that case the brake would not require quite so much adjusting to keep the applied load on the machine constant. Since Prony brake tests are always of considerable duration, the lining used must be able to withstand continuous running. It seems that the various preparations of asbestos have shown a fairly constant coefficient of friction with varying pressure,and furthermore continuous running would not be very likely to affect its properties, provided proper provision is made for carrying away the heat due to friction. Asbestos is affected but little by an increase of temperature and no doubt the samples having this substance as a body would prove the most satisfactory for Prony brake use.

The fact that these tests were not run beyond nineteen horsepower on account of excessive heating would seem to indicate that these linings would operate more satisfactorily on small brakes absorbing light horsepowers.

One other test was run, however, that is not recorded here. It was a sort of preliminary test for the series of endurance tests

that it was hoped could be run. Sample F was placed in the apparatus, and a load of eight horsepower placed on the brake. This ran continuously for three and one-quarter hours and at the end of that time the lining was worn down to about three-fourths of its original thickness. New pieces of the same sample were then put on the brake and a load of twenty horsepower applied. This ran continuously for two and one-half hours and at the end of that time the lining was worn to about one-fourth of its original thickness. As a result of these tests, one might be led to suppose that the wear of these linings would be so rapid at any higher loads that their use would be unsatisfactory due to the necessity of replacing them so frequently and if the tests were of a longer duration the samples would have to be replaced during the test which would be inconvenient and interrupt the taking of data.

TESTS OF BRAKE LININGS

DATA SHEET No. 1.

Sample: A-3

Date: April, 23, 1912

Net Wt. on Scales lbs.	Tangential Force. lbs.	Compression of Spring inches	Pressure on Blocks lbs.	Coefficient of Friction	Remarks
10.	43.7	0.064	154.	0.271	
15.	65.6	0.083	208.	0.301	
20.	87.4	0.100	256.	0.326	
25.	109.2	0.115	306.	0.341	
30.	131.1	0.140	384.	0.326	
35.	152.9	0.230	708.	0.206	Heated
40.	174.8	0.300	952.	0.175	Smoked

TESTS OF BRAKE LININGS

DATA SHEET No. 2.

Sample: A-2 Date: April, 24, 1912.

Net Wt. on Scales lbs.	Tangential Force. lbs.	Compression of Spring inches	Pressure on Blocks lbs.	Coefficient of Friction	Remarks
5.	21.9	0.075	186.	0.113	
10.	43.7	0.098	252.	0.166	
15.	65.6	0.114	304.	0.206	
20.	87.4	0.132	358.	0.233	
25.	109.2	0.158	444.	0.236	
30.	131.1	0.178	520.	0.241	
35.	152.9	0.200	604.	0.242	
40.	174.8	0.220	676.	0.247	
45.	195.7	0.238	736.	0.254	
50.	217.0	0.256	796.	0.260	

TESTS OF BRAKE LININGS

DATA SHEET No. 3.

Sample: A-4 Date: April 27, 1912.

Net Wt. on Scales lbs.	Tangential Force. lbs.	Compression of Spring. inches	Pressure on Blocks lbs.	Coefficient of Friction	Remarks
5.	21.9	0.048	116.	0.180	
10.	43.7	0.092	232.	0.179	
15.	65.6	0.128	354.	0.178	
20.	87.4	0.167	472.	0.177	
25.	109.2	0.198	596.	0.175	
30.	131.1	0.235	722.	0.174	
35.	152.9	0.276	866.	0.169	Heated
40.	174.8	0.315	1004.	0.166	Smoked

TESTS OF BRAKE LININGS

DATA SHEET No. 4.

Sample: A-1.

Date: April 27, 1912.

Net Wt. on Scales lbs.	Tangential Force. lbs.	Compression of Spring inches	Pressure on Blocks lbs.	Coefficient of Friction	Remarks
5.	21.9	0.017	44.	0.470	
10.	43.7	0.042	102.	0.409	
15.	65.6	0.062	150.	0.417	
20.	87.4	0.085	212.	0.394	
25.	109.2	0.118	312.	0.335	
30.	131.1	0.135	368.	0.341	
35.	152.9	0.162	456.	0.320	
40.	174.8	0.180	524.	0.318	
45.	195.7	0.200	604.	0.309	
50.	217.0	0.220	676.	0.308	
55.	238.7	0.240	742.	0.307	
60.	260.0	0.260	812.	0.306	
70.	304.0	0.300	952.	0.305	

TESTS OF BRAKE LININGS

DATA SHEET No. 5.

Sample: B

Date: April 27, 1912.

Net Wt. on Scales lbs.	Tangential Force. lbs.	Compression of Spring inches	Pressure on Blocks lbs.	Coefficient of Friction	Remarks
5.	21.9	0.023	56.	0.374	
10.	43.7	0.048	116.	0.360	
15.	65.6	0.073	180.	0.350	
20.	87.4	0.093	236.	0.353	
25.	109.2	0.120	320.	0.327	
30.	131.1	0.140	384.	0.326	
35.	152.9	0.160	448.	0.326	
40.	174.8	0.180	524.	0.319	
45.	195.7	0.220	676.	0.278	

TESTS OF BRAKE LININGS

DATA SHEET No. 6.

Sample: C

Date: April 27, 1912.

Net Wt. on Scales lbs.	Tangential Force. lbs.	Compression of Spring. inches	Pressure on Blocks lbs.	Coefficient of Friction	Remarks
5.	21.9	0.030	72.	0.291	
10.	43.7	0.058	140.	0.298	
15.	65.6	0.080	198.	0.317	
20.	87.4	0.100	256.	0.326	
25.	109.2	0.125	336.	0.311	
30.	131.1	0.160	448.	0.279	
35.	152.9	0.185	544.	0.268	
40.	174.8	0.213	652.	0.257	
45.	195.7	0.235	722.	0.258	
50.	217.0	0.260	812.	0.255	Smoked.

TESTS OF BRAKE LININGS

DATA SHEET No. 7.

Sample: D-G-A

Date: April 27, 1912.

Net Wt. on Scales lbs.	Tangential Force. lbs.	Compression of Spring. inches	Pressure on Blocks lbs.	Coefficient of Friction	Remarks
5.	21.9	0.015	38.	0.550	
10.	43.7	0.038	92.	0.453	
15.	65.6	0.062	148.	0.443	
20.	87.4	0.090	226.	0.369	
25.	109.2	0.124	334.	0.313	
30.	131.1	0.145	400.	0.313	
35.	152.9	0.175	502.	0.291	
40.	174.8	0.200	604.	0.277	
45.	195.7	0.272	854.	0.219	
50.	217.0	0.300	952.	0.218	

TESTS OF BRAKE LININGS

DATA SHEET NO.8.

Sample: D-G-AA Date: April 27, 1912.

Net Wt. on Scales lbs.	Tangential Force. lbs.	Compression of Spring. inches	Pressure on Blocks lbs.	Coefficient of Friction	Remarks
5.	21.9	0.024	56.	0.373	
10.	43.7	0.045	104.	0.387	
15.	65.6	0.065	156.	0.401	
20.	87.4	0.080	198.	0.422	
25.	109.2	0.118	312.	0.335	
30.	131.1	0.140	384.	0.326	
35.	152.9	0.180	524.	0.279	
40.	174.8	0.210	644.	0.259	
45.	195.7	0.235	722.	0.259	
50.	217.0	0.265	828.	0.251	

TESTS OF BRAKE LININGS

DATA SHEET No. 9.

Sample: D-G-AAA　　　　Date: April 27, 1912.

Net Wt. on Scales lbs.	Tangential Force lbs.	Compression of Spring inches	Pressure on Blocks lbs.	Coefficient of Friction	Remarks
5.	21.9	0.019	44.	0.485	
10.	43.7	0.038	92.	0.458	
15.	65.6	0.060	144.	0.435	
20.	87.4	0.078	194.	0.430	
25.	109.2	0.102	260.	0.401	
30.	131.1	0.134	364.	0.345	
35.	152.9	0.156	436.	0.335	
40.	174.8	0.178	516.	0.324	
45.	195.7	0.195	584.	0.319	
50.	217.0	0.230	708.	0.294	
55.	238.7	0.242	748.	0.305	
60.	260.0	0.270	848.	0.293	
65.	282.0	0.285	902.	0.298	
70.	304.0	0.310	968.	0.300	
75.	325.4	0.330	1054.	0.295	

TESTS OF BRAKE LININGS

DATA SHEET No. 10.

Sample : E-4 Date: May 1, 1912.

Net Wt. on Scales lbs.	Tangential Force. lbs.	Compression of Spring. inches	Pressure on Blocks lbs.	Coefficient of Friction	Remarks
20.	87.4	0.170	484.	0.178	
25.	109.2	0.190	564.	0.186	
30.	131.1	0.210	644.	0.194	
35.	152.9	0.228	702.	0.208	
40.	174.8	0.250	782.	0.213	
45.	195.7	0.275	864.	0.216	
50.	217.0	0.300	952.	0.218	
55.	238.7	0.320	1020.	0.223	
60.	260.0	0.350	1124.	0.221	

TESTS OF BRAKE LININGS

DATA SHEET No. 11.

Sample: E-7 Date: May 1, 1912.

Net Wt. on Scales lbs.	Tangential Force. lbs.	Compression of Spring. inches	Pressure on Blocks. lbs.	Coefficient of Friction	Remarks
10.	43.7	0.050	120.	0.348	
15.	65.6	0.073	180.	0.348	
20.	87.4	0.100	256.	0.326	
25.	109.2	0.125	336.	0.311	
30.	131.1	0.145	400.	0.313	
35.	152.9	0.160	448.	0.326	
40.	174.8	0.175	502.	0.332	
45.	195.7	0.190	564.	0.332	
50.	217.0	0.210	644.	0.322	
55.	238.7	0.240	742.	0.307	
60.	260.0	0.275	864.	0.288	

TESTS OF BRAKE LININGS

DATA SHEET No. 12.

Sample: F Date: May 2, 1912.

Net Wt. on Scales lbs.	Tangential Force. lbs.	Compression of Spring inches	Pressure on Blocks lbs.	Coefficient of Friction	Remarks
5.	21.9	0.024	56.	0.373	
10.	43.7	0.048	116.	0.359	
15.	65.6	0.085	212.	0.296	
20.	87.4	0.115	306.	0.274	
25.	109.2	0.150	416.	0.251	
30.	131.1	0.180	524.	0.239	
35.	152.9	0.210	644.	0.227	
40.	174.8	0.235	722.	0.231	
45.	195.7	0.260	812.	0.230	
50.	217.0	0.300	952.	0.218	

TESTS OF BRAKE LININGS

DATA SHEET No. 13.

Sample: H

Date: May 4, 1912.

Net Wt. on Scales lbs.	Tangential Force. lbs.	Compression of Spring inches	Pressure on Blocks lbs.	Coefficient of Friction	Remarks
5.	21.9	0.035	84.	0.250	
10.	43.7	0.070	168.	0.248	
15.	65.6	0.100	256.	0.245	
20.	87.4	0.130	356.	0.234	
25.	109.2	0.170	484.	0.216	
30.	131.1	0.190	564.	0.222	
35.	152.9	0.210	644.	0.226	
40.	174.8	0.225	692.	0.242	
45.	195.7	0.240	742.	0.253	
50.	217.0	0.255	794.	0.261	
55.	238.7	0.280	884.	0.258	

TESTS OF BRAKE LININGS

DATA SHEET No. 14.

Sample: I-1

Date: May 4, 1912.

Net Wt. on Scales lbs.	Tangential Force. lbs.	Compression of Spring inches	Pressure on Blocks lbs.	Coefficient of Friction	Remarks
5.	21.9	0.022	52.	0.402	
10.	43.7	0.048	116.	0.360	
15.	65.6	0.075	184.	0.342	
20.	87.4	0.098	252.	0.332	
25.	109.2	0.125	336.	0.311	
30.	131.1	0.155	432.	0.290	
35.	152.9	0.180	524.	0.278	
40.	174.8	0.200	604.	0.276	
45.	195.7	0.220	674.	0.277	
50.	217.0	0.240	742.	0.279	
55.	238.7	0.265	828.	0.276	
60.	260.0	0.285	902.	0.275	
65.	282.0	0.310	968.	0.279	

TESTS OF BRAKE LININGS

DATA SHEET No. 15.

Sample: I-2 Date: May 6, 1912.

Net Wt. on Scales lbs.	Tangential Force. lbs.	Compression of Spring inches	Pressure on Blocks lbs.	Coefficient of Friction	Remarks
5.	21.9	0.035	84.	0.249	
10.	43.7	0.073	180.	0.232	
15.	65.6	0.105	272.	0.231	
20.	87.4	0.135	368.	0.227	
25.	109.2	0.150	416.	0.251	
30.	131.1	0.170	484.	0.259	
35.	152.9	0.190	564.	0.258	
40.	174.8	0.205	624.	0.267	
45.	195.7	0.225	692.	0.270	
50.	217.0	0.245	760.	0.273	
55.	238.7	0.270	848.	0.265	
60.	260.0	0.300	952.	0.261	

TESTS OF BRAKE LININGS

DATA SHEET No. 16.

Sample: J

Date: May 6, 1912.

Net Wt. on Scales lbs.	Tangential Force. lbs.	Compression of Spring inches	Pressure on Blocks lbs.	Coefficient of Friction	Remarks
5.	21.9	0.050	120.	0.174	
10.	43.7	0.105	272.	0.153	
15.	65.6	0.150	416.	0.151	
20.	87.4	0.188	560.	0.149	
25.	109.2	0.230	708.	0.148	
30.	131.1	0.290	916.	0.143	

TESTS OF BRAKE LININGS

DATA SHEET No. 17.

Sample: K-1 Date: May 6, 1912.

Net Wt. on Scales lbs.	Tangential Force. lbs.	Compression of Spring inches	Pressure on Blocks lbs.	Coefficient of Friction	Remarks
5.	21.9	0.035	84.	0.249	
10.	43.7	0.068	164.	0.237	
15.	65.6	0.105	272.	0.231	
20.	87.4	0.134	364.	0.229	
25.	109.2	0.163	462.	0.226	
30.	131.1	0.190	564.	0.223	
35.	152.9	0.215	660.	0.221	
40.	174.8	0.245	760.	0.220	
45.	195.7	0.270	848.	0.220	
50.	217.0	0.300	952.	0.218	

TESTS OF BRAKE LININGS

DATA SHEET No. 18.

Sample: K-2

Date: May 6, 1912.

Net Wt. on Scales lbs.	Tangential Force. lbs.	Compression of Spring inches	Pressure on Blocks lbs.	Coefficient of Friction	Remarks
5.	21.9	0.024	56.	0.373	
10.	43.7	0.052	124.	0.337	
15.	65.6	0.090	226.	0.282	
20.	87.4	0.120	320.	0.261	
25.	109.2	0.150	416.	0.251	
30.	131.1	0.185	544.	0.231	
35.	152.9	0.210	644.	0.227	
40.	174.8	0.235	722.	0.231	
45.	195.7	0.265	828.	0.226	
50.	217.0	0.290	920.	0.227	
55.	238.7	0.320	1020.	0.224	

TABLE I.

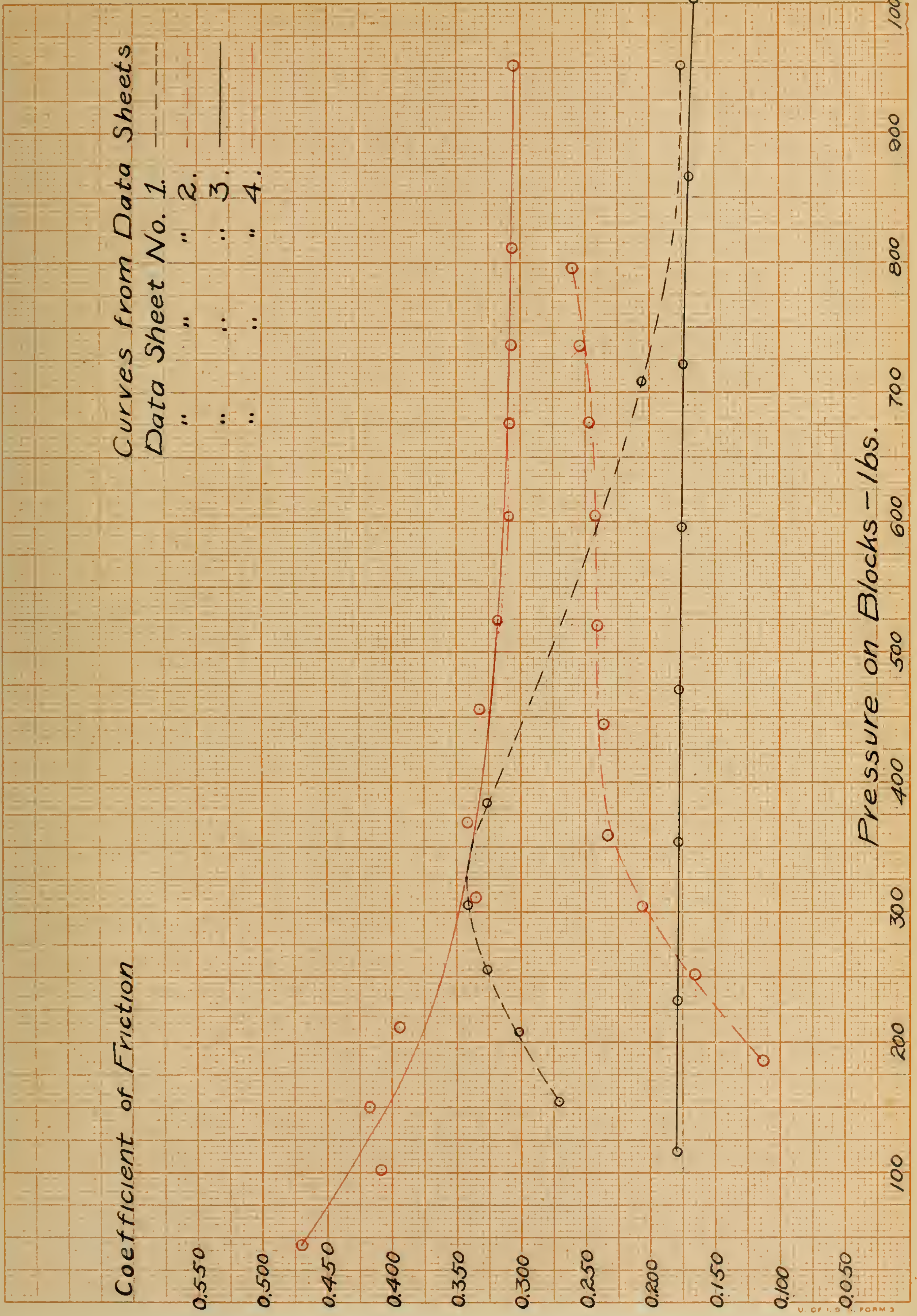
Weight on Scales pounds	Average Revolutions per Minute	Horsepower
5.	578.	1.33
10.	576.	2.55
15.	574.	3.95
20.	572.	5.27
25.	570.	6.55
30.	568.	7.85
35.	566.	9.12
40.	564.	10.39
45.	562.	11.63
50.	560.	12.90
55.	558.	14.10
60.	556.	15.35
65.	554.	16.58
70.	552.	17.75
75.	550.	18.90

The figures in column three were calculated by formula 15.

TABLE II.

Coefficient of Friction with Varying Horsepower

Sample	Horsepower														
	1.33	2.55	3.95	5.27	6.55	7.85	9.12	10.39	11.63	12.90	14.10	15.35	16.58	17.75	18.90
A-3		.271	.301	.326	.341	.326	.206	.175							
A-2	.113	.166	.206	.233	.236	.241	.242	.247	.254	.260					
A-4	.180	.179	.178	.177	.175	.174	.169	.166							
A-1	.470	.409	.417	.394	.335	.341	.320	.318	.309	.308	.307	.306		.305	
B	.374	.360	.350	.353	.327	.326	.326	.319	.278						
C	.291	.298	.317	.326	.311	.279	.268	.257	.258	.255					
D-G-A	.550	.453	.443	.369	.313	.313	.291	.277	.219	.218					
D-G-AA	.373	.387	.401	.422	.335	.326	.279	.259	.259	.251					
D-G-AAA	.485	.458	.435	.430	.401	.345	.335	.324	.319	.294	.305	.293	.298	.300	.295
E-4				.178	.186	.194	.208	.213	.216	.218	.223	.221			
E-7		.348	.348	.326	.311	.313	.326	.332	.332	.322	.307	.288			
F	.373	.359	.296	.274	.251	.239	.227	.231	.230	.218					
H	.250	.248	.245	.234	.216	.222	.226	.242	.253	.261	.258				
I-1	.402	.360	.342	.332	.311	.290	.278	.276	.277	.279	.276	.275	.279		
I-2	.249	.232	.231	.227	.251	.259	.258	.267	.270	.273	.265	.261			
J	.174	.153	.151	.149	.148	.143									
K-1	.249	.237	.231	.229	.226	.223	.221	.220	.220	.218					
K-2	.373	.337	.282	.261	.251	.231	.227	.231	.226	.227	.224				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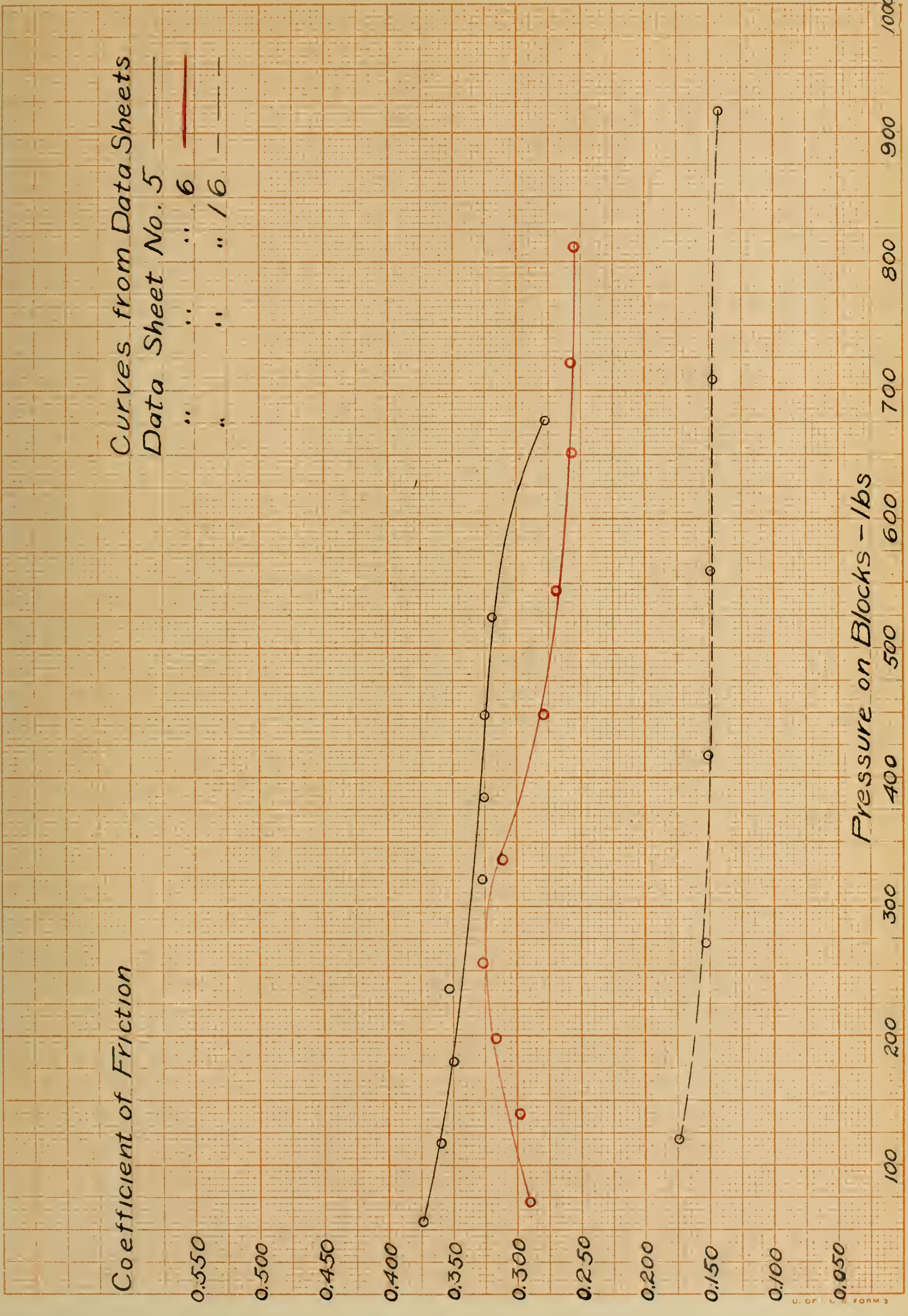
" " " 3.
" " " 4.
Coefficient of Friction
Pressure on Blocks - lbs.
0.550
0.500
0.450
0.400
0.350
0.300
0.250
0.200
0.150
0.100
0.050
100
200
300
400
500
600
700
800
900
1000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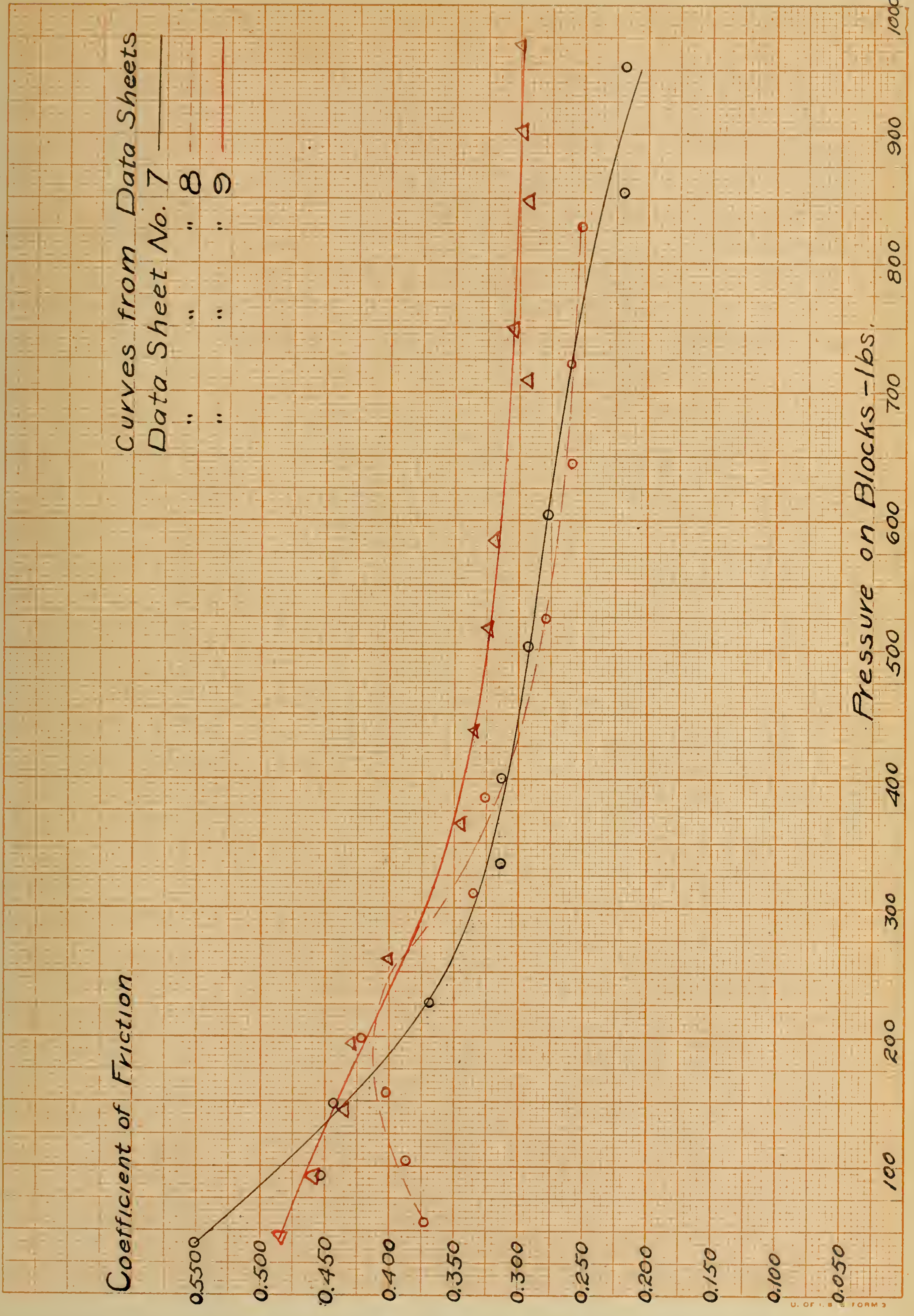
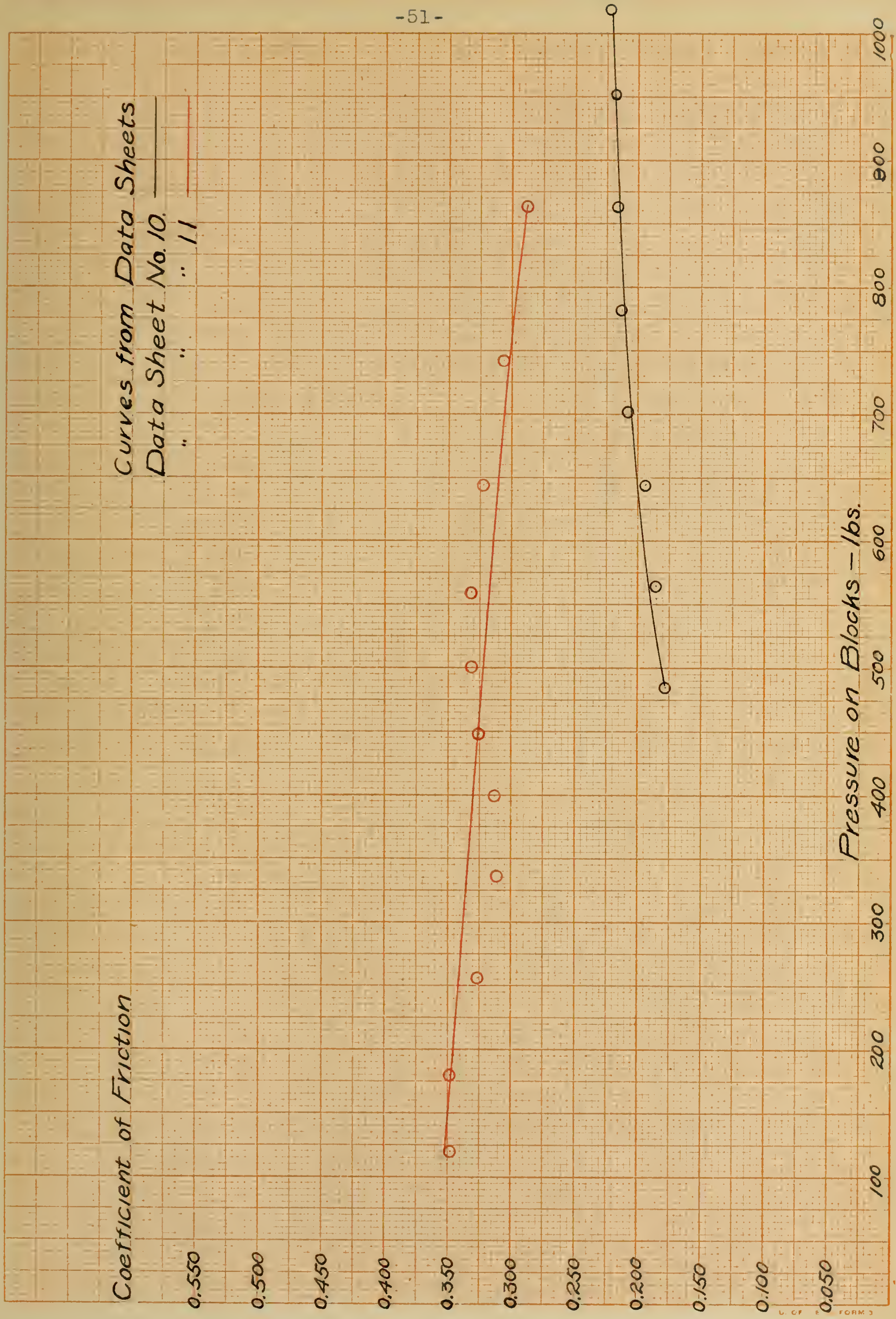
Coefficient of Friction
0.550
0.500
0.450
0.400
0.350
0.300
0.250
0.200
0.150
0.100
0.050
Pressure on Blocks - lbs
100
200
300
400
500
600
700
800
900
1000


Coefficient of Friction
Curves from Data Sheets
Data Sheet No. 7
" " " 8
" " " 9
Pressure on Blocks - lbs.
0.5500
0.500
0.450
0.400
0.350
0.300
0.250
0.200
0.150
0.100
0.050
100
200
300
400
500
600
700
800
900
1000
U. OF I. S. S. FORM 3


Coefficient of Friction
Curves from Data Sheets
Data Sheet No. 10.
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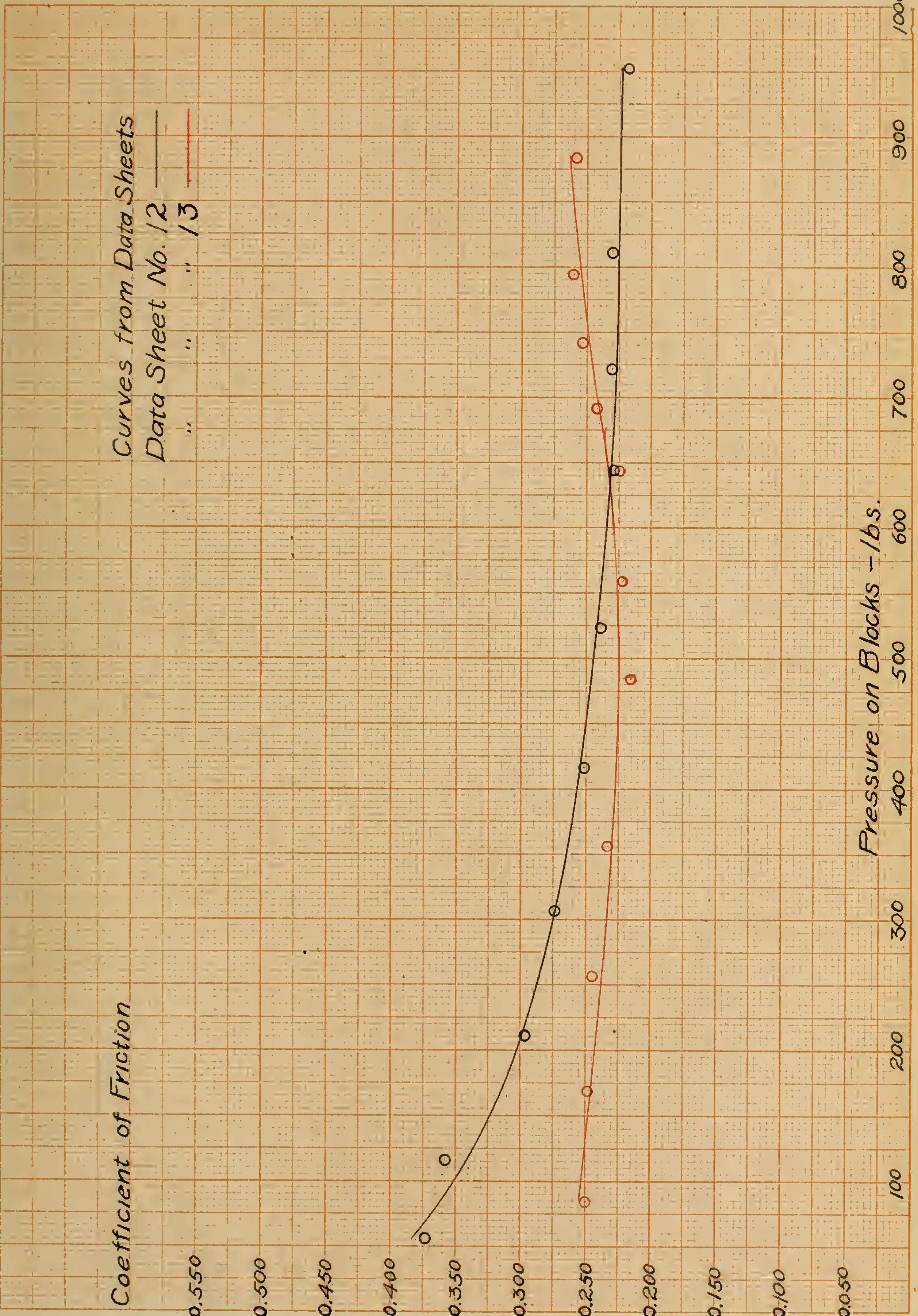
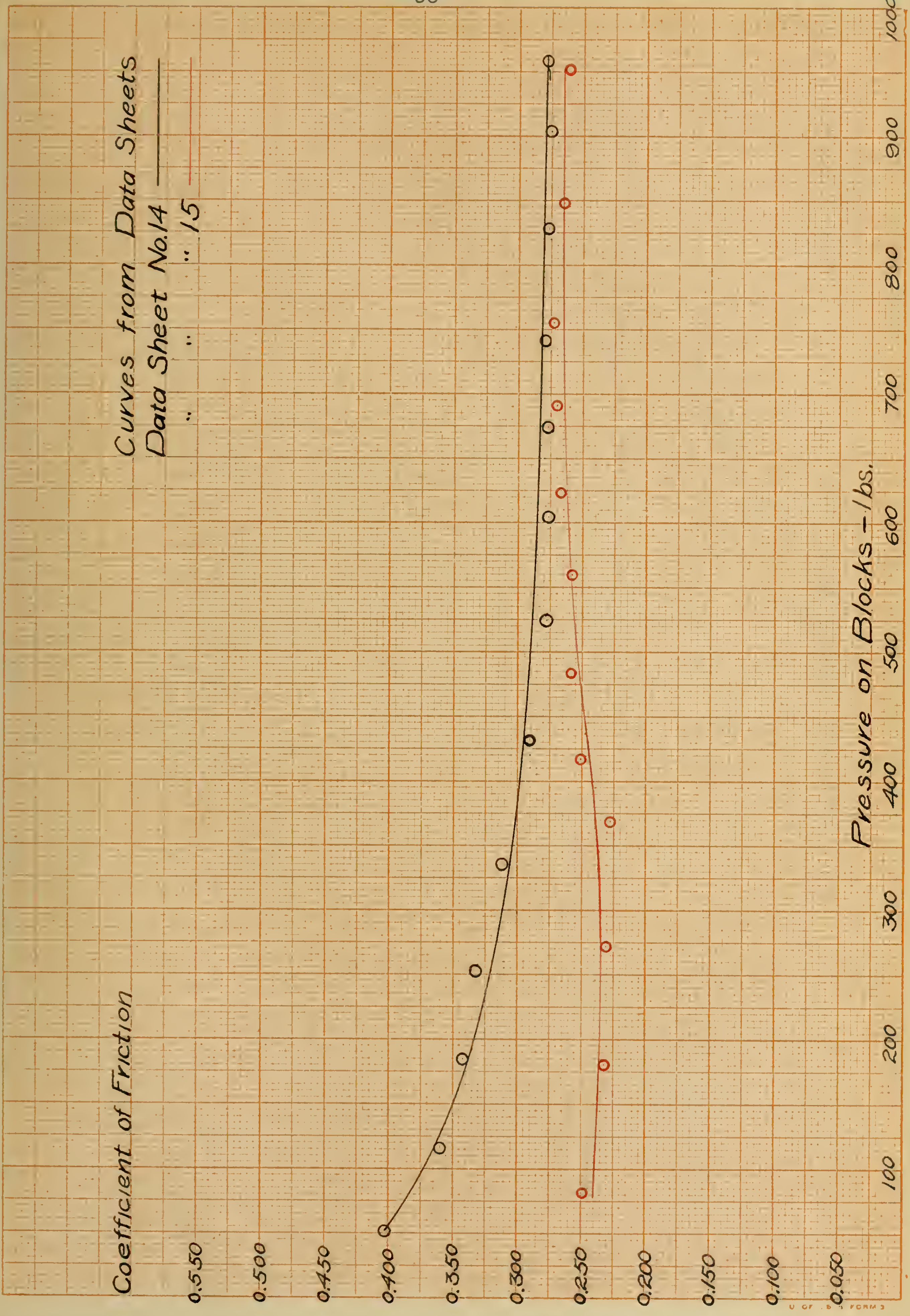
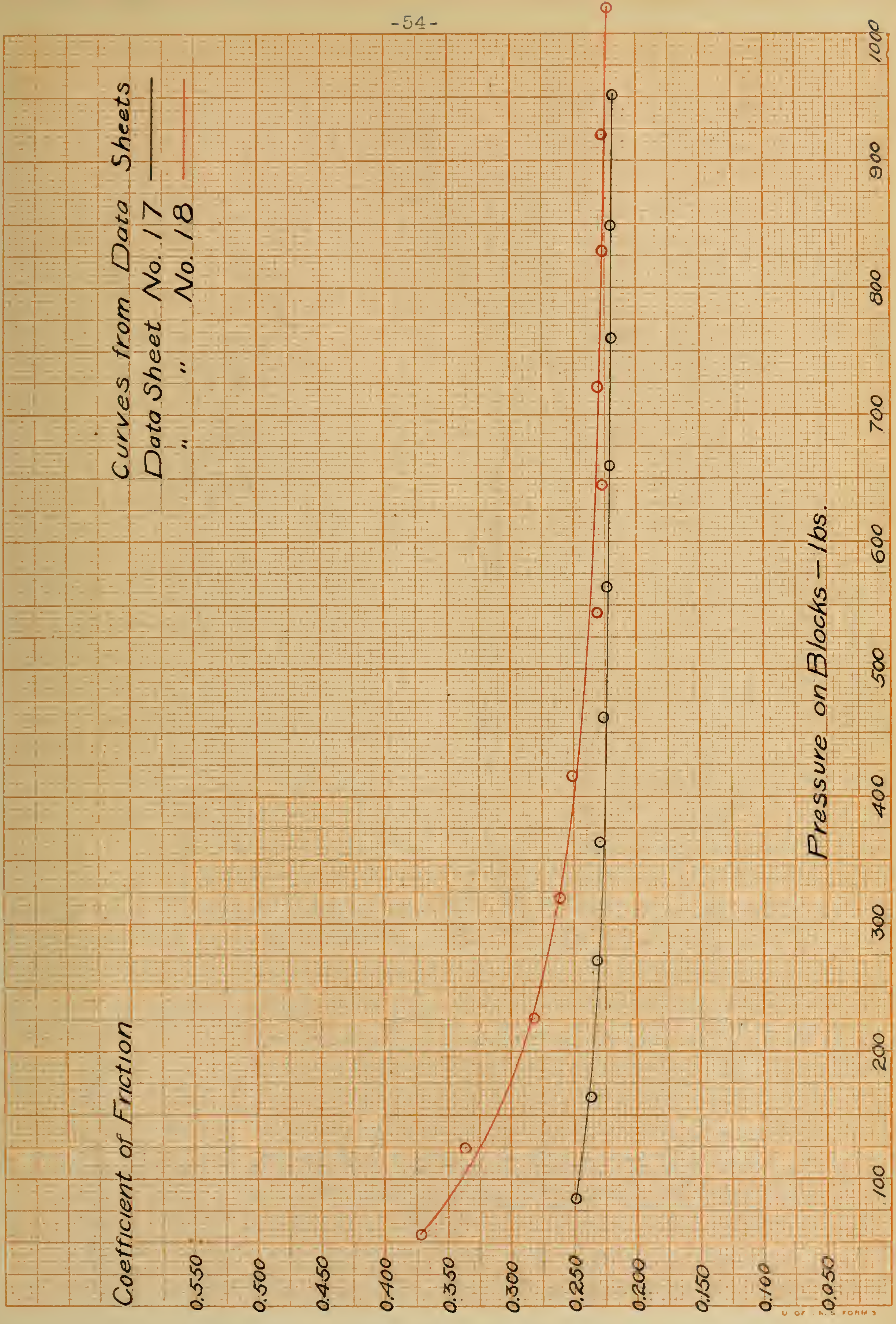
Pressure on Blocks – lbs.
0.550
0.500
0.450
0.400
0.350
0.300
0.250
0.200
0.150
0.100
0.050
100
200
300
400
500
600
700
800
900
1000
FORM 3


Coefficient of Friction
Curves from Data Sheets
Data Sheet No. 12
" " 13
Pressure on Blocks – lbs.
0.550
0.500
0.450
0.400
0.350
0.300
0.250
0.200
0.150
0.100
0.050
100
200
300
400
500
600
700
800
900
1000


Coefficient of Friction
Curves from Data Sheets
Data Sheet No.14
" " 15
0.550
0.500
0.450
0.400
0.350
0.300
0.250
0.200
0.150
0.100
0.050
100
200
300
400
500
600
700
800
900
1000
Pressure on Blocks - lbs.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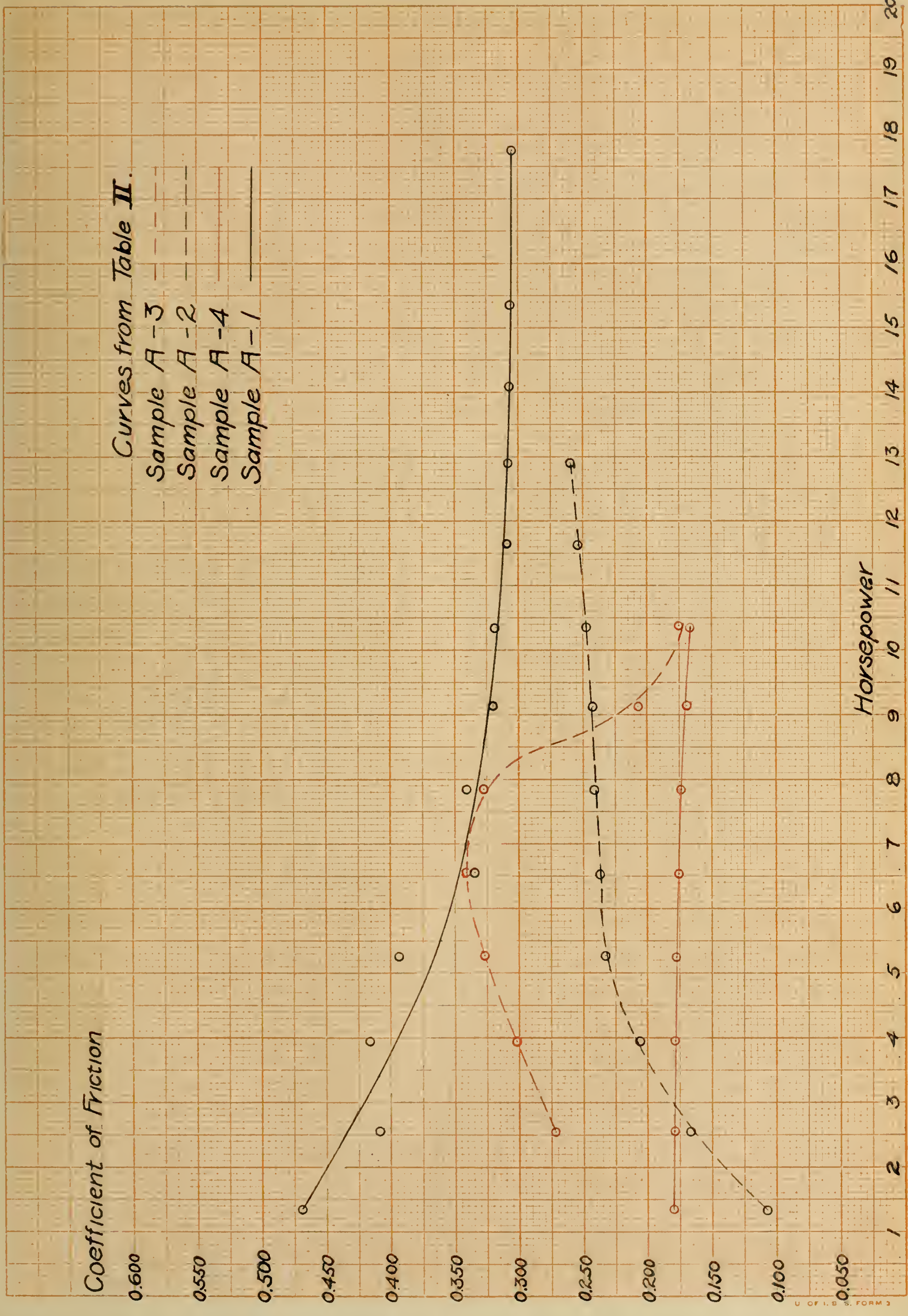
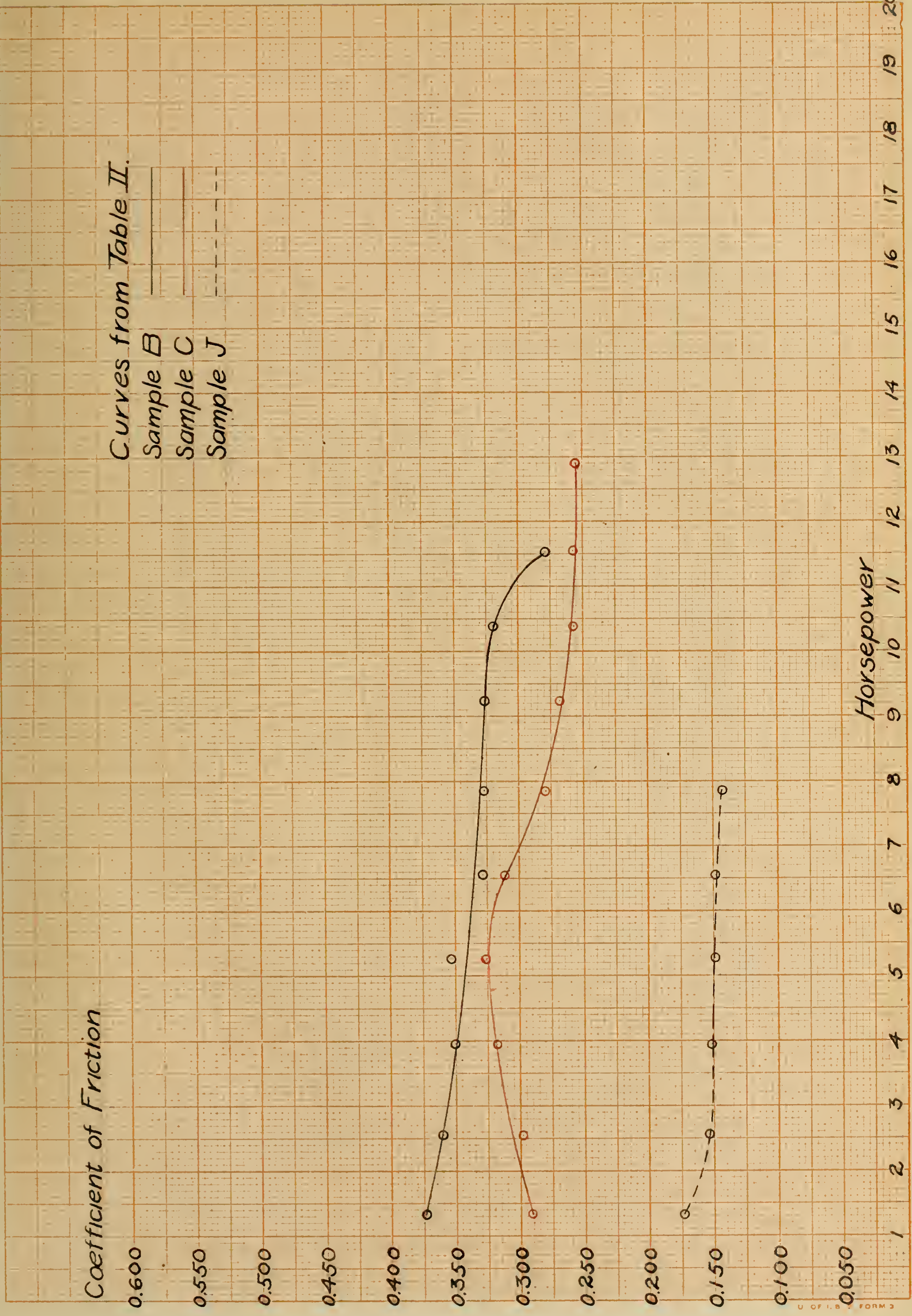
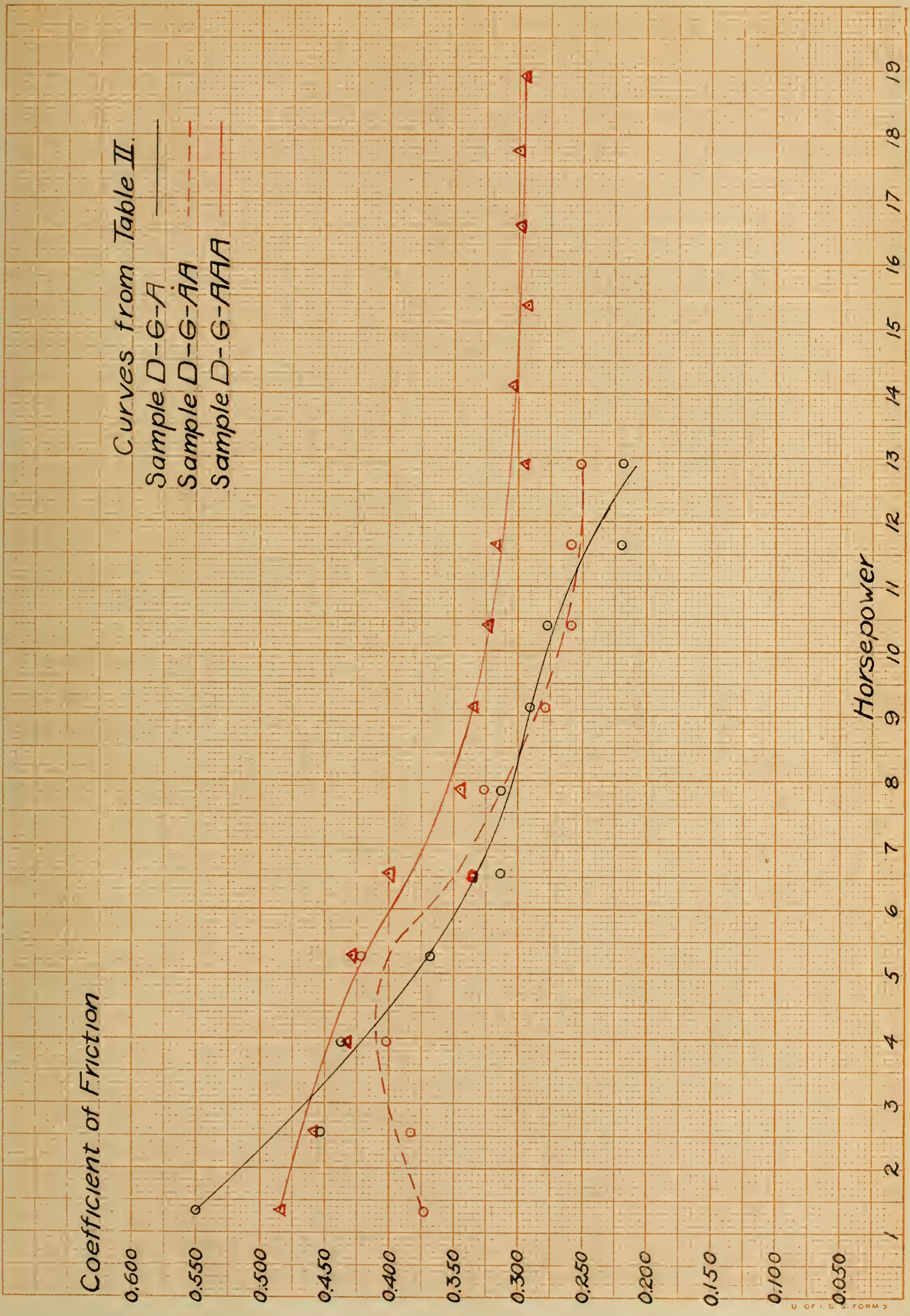
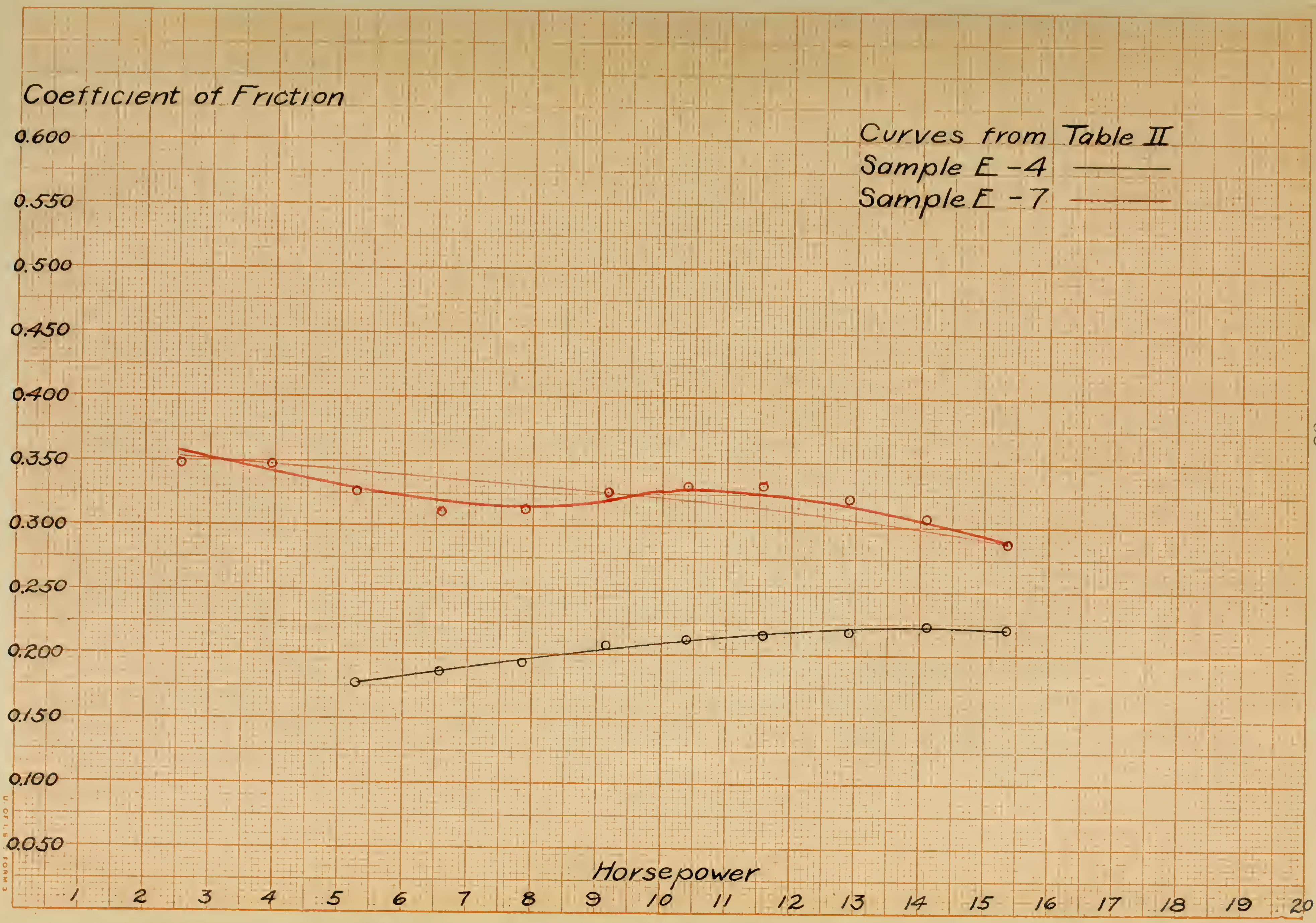
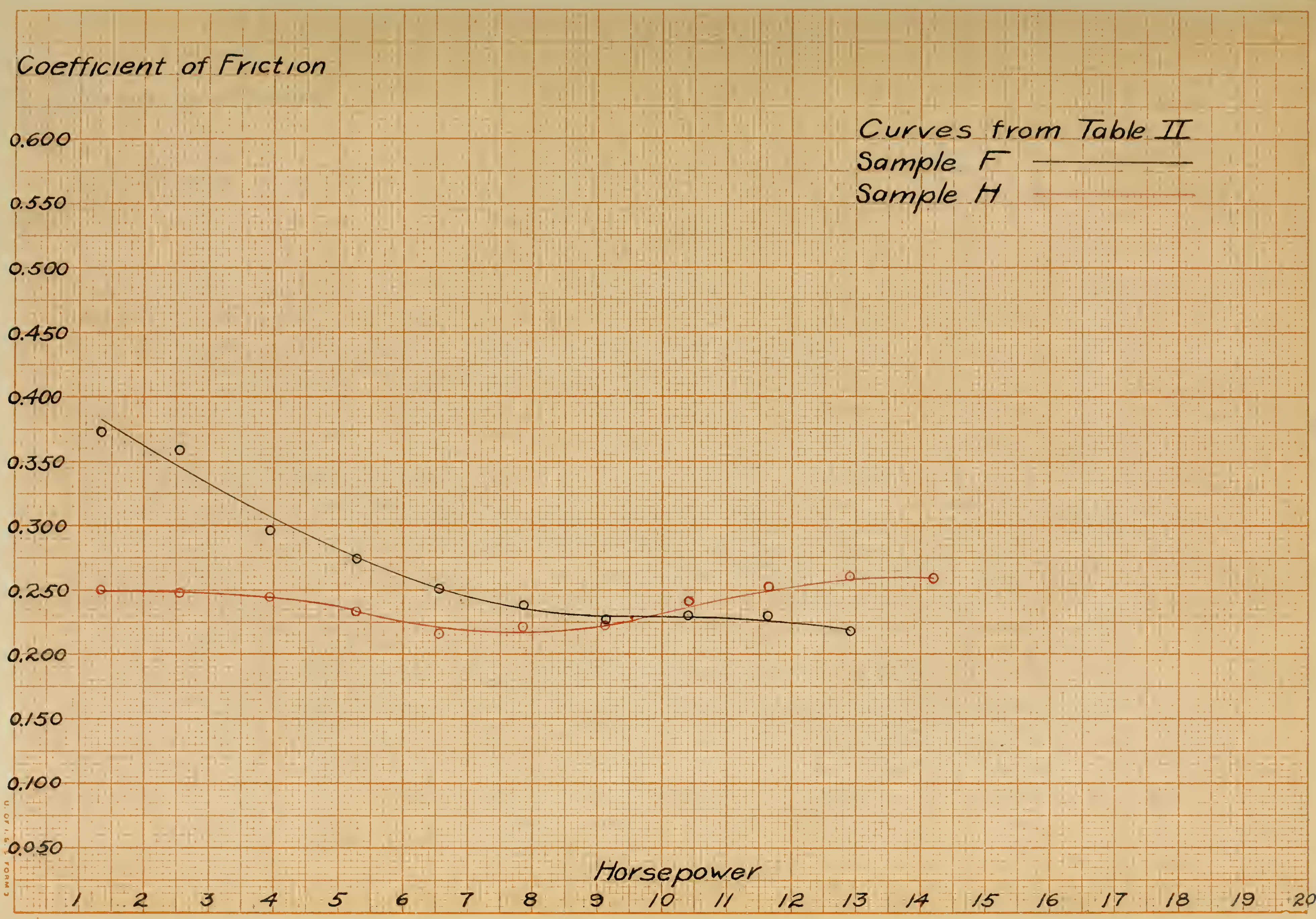
Data Sheet No. 17
" " No. 18
Coefficient of Friction
0.550
0.500
0.450
0.400
0.350
0.300
0.250
0.200
0.150
0.100
0.050
Pressure on Blocks – lbs.
100
200
300
400
500
600
700
800
900
1000

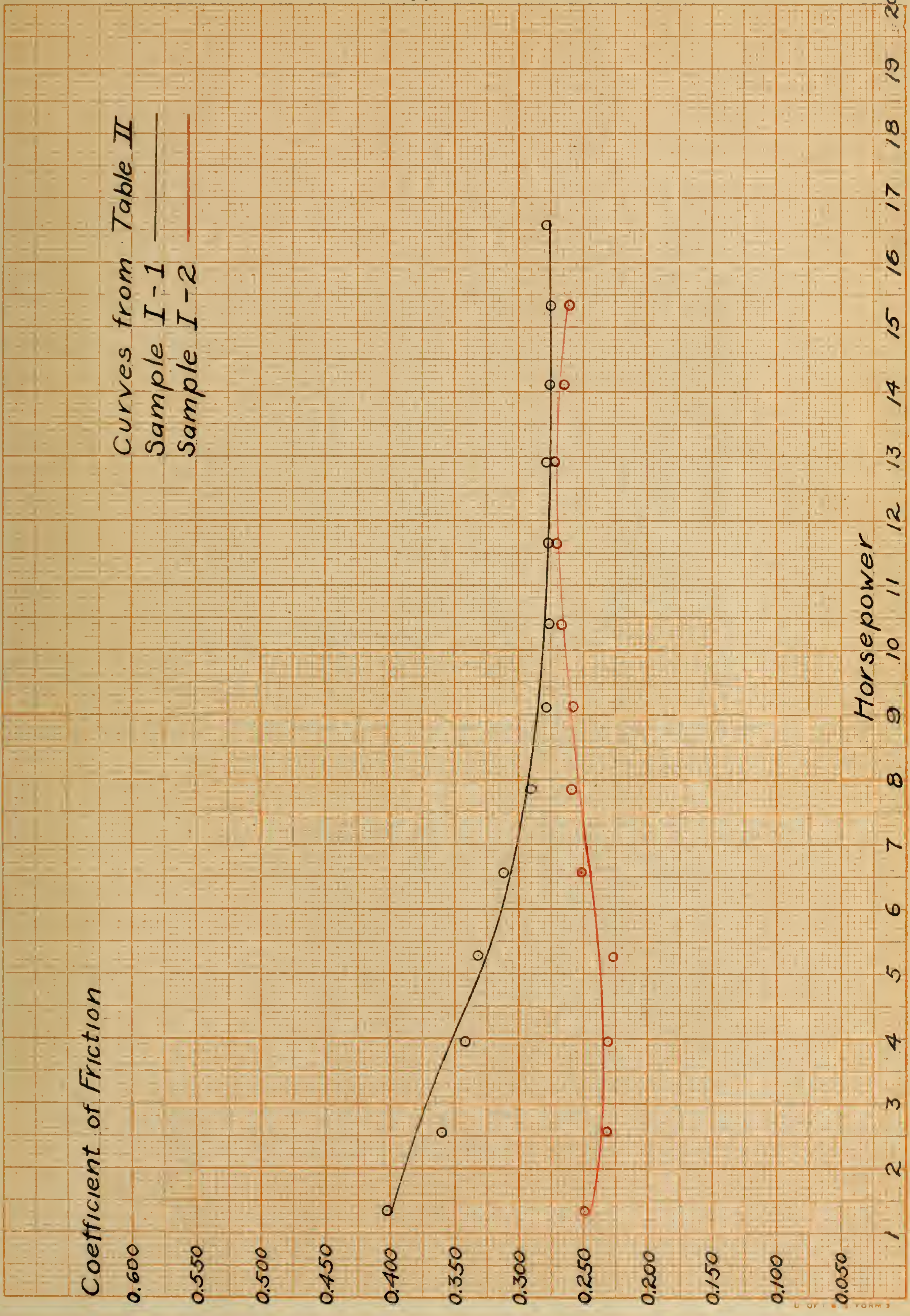

Curves from Table II.
Sample A-3
Sample A-2
Sample A-4
Sample A-1
Coefficient of Friction
0.600
0.550
0.500
0.450
0.400
0.350
0.300
0.250
0.200
0.150
0.100
0.050
Horsepower
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20

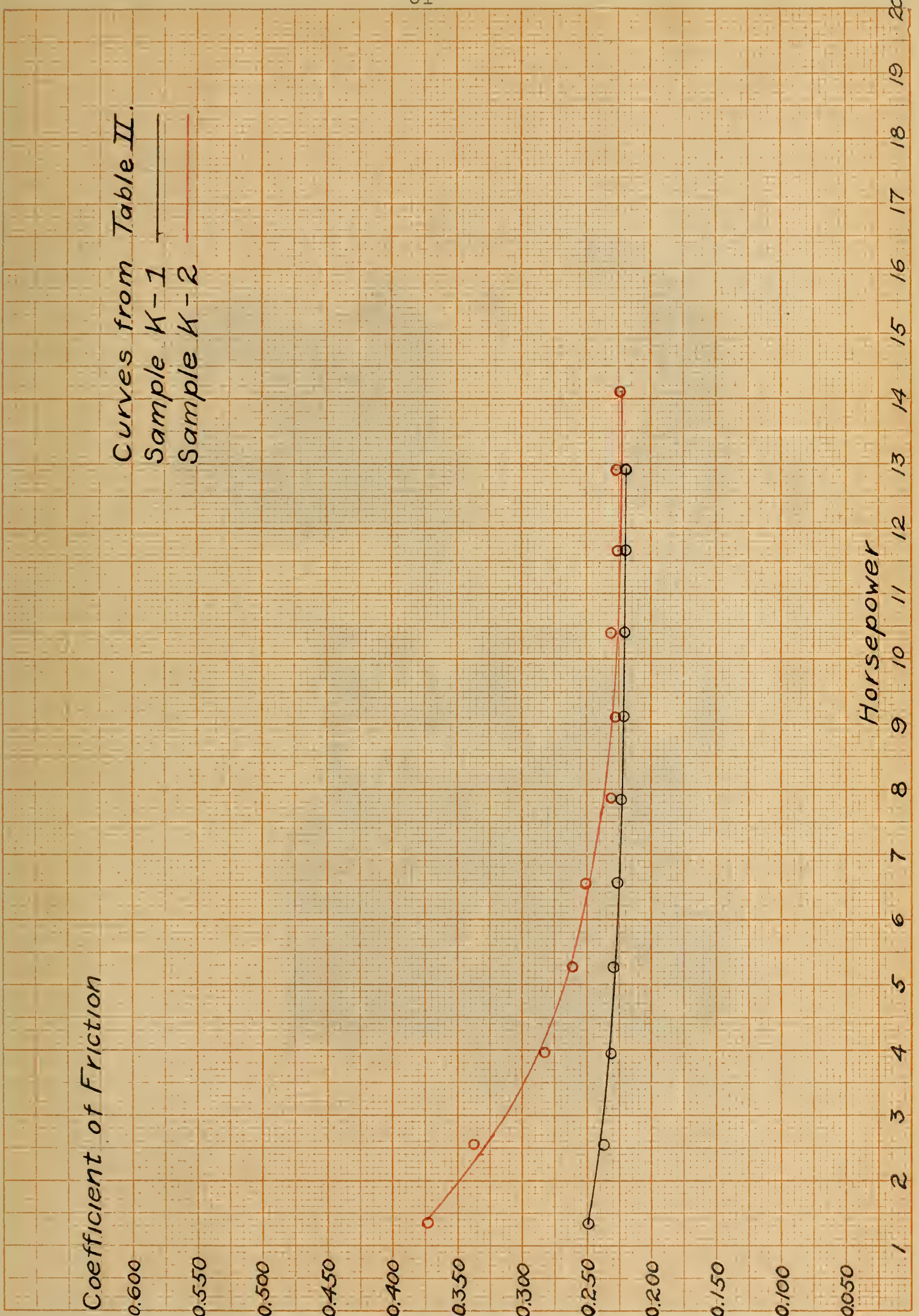

Coefficient of Friction
0.600
0.550
0.500
0.450
0.400
0.350
0.300
0.250
0.200
0.150
0.100
0.050
Horsepower
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
Curves from Table II.
Sample B
Sample C
Sample J

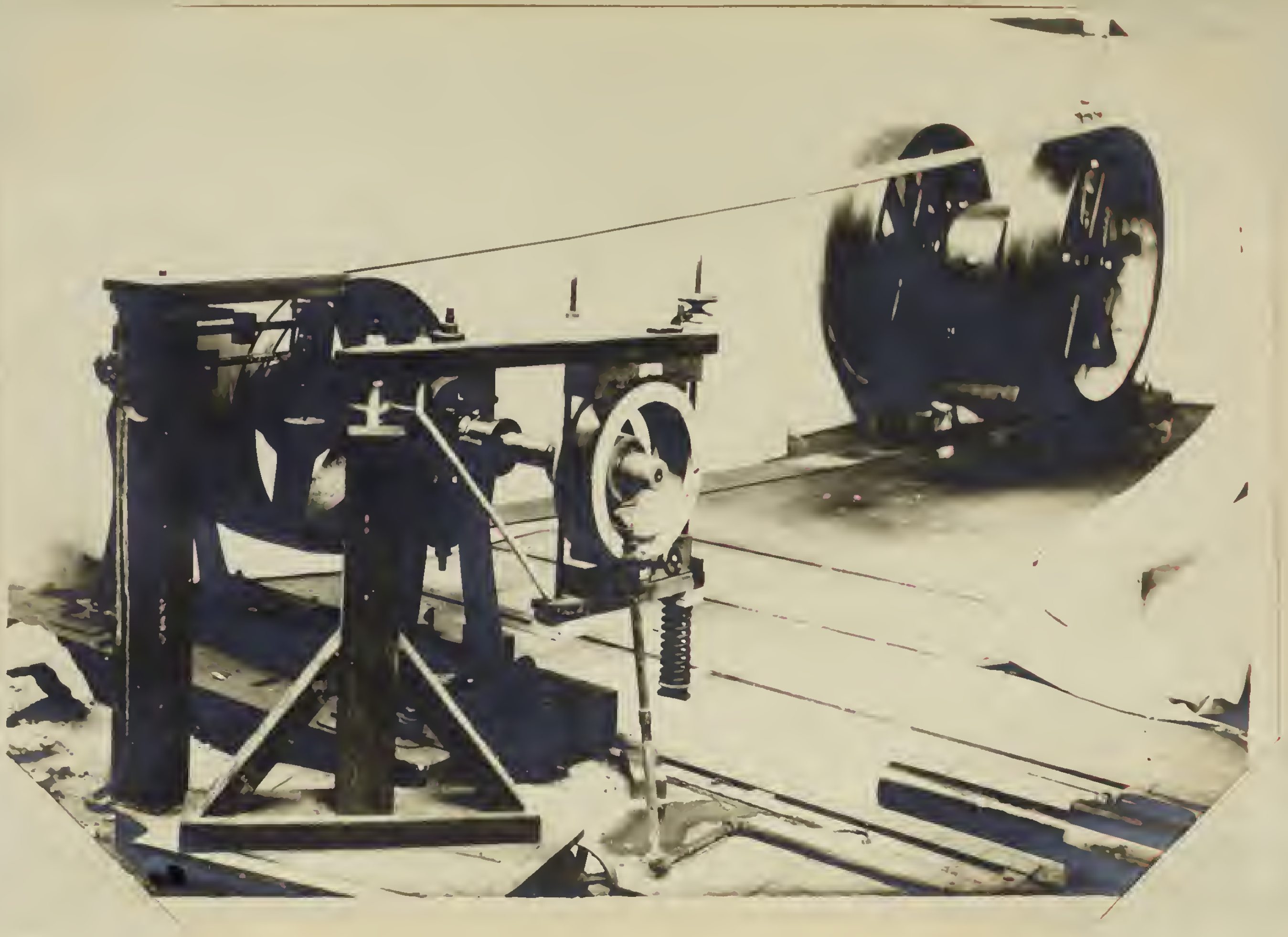

Coefficient of Friction
0.600
0.550
0.500
0.450
0.400
0.350
0.300
0.250
0.200
0.150
0.100
0.050
Horsepower
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
Curves from Table II.
Sample D-G-A
Sample D-G-AA
Sample D-G-AAA


Coefficient of Friction
0.600
0.550
0.500
0.450
0.400
0.350
0.300
0.250
0.200
0.150
0.100
0.050
Curves from Table II
Sample E -4
Sample E -7
Horsepower
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20


Coefficient of Friction
Curves from Table II
Sample F
Sample H
0.600
0.550
0.500
0.450
0.400
0.350
0.300
0.250
0.200
0.150
0.100
0.050
Horsepower
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
U. OF I. S. S. FORM 3

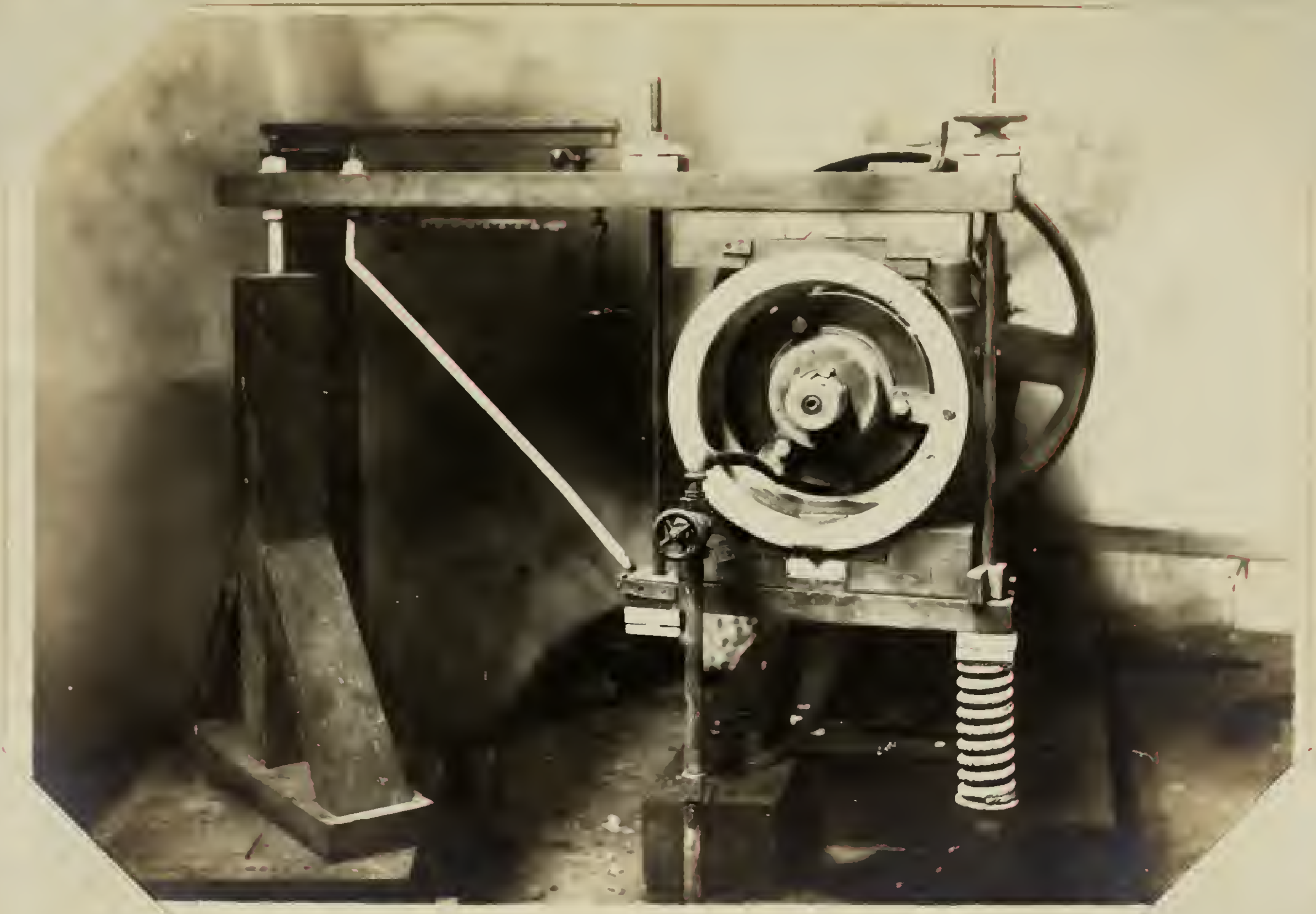

Coefficient of Friction
0.600
0.550
0.500
0.450
0.400
0.350
0.300
0.250
0.200
0.150
0.100
0.050
Horsepower
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
Curves from Table II
Sample I-1
Sample I-2


Curves from Table II.
Sample K-1
Sample K-2
Coefficient of Friction
0.600
0.550
0.500
0.450
0.400
0.350
0.300
0.250
0.200
0.150
0.100
0.050
Horsepower
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20

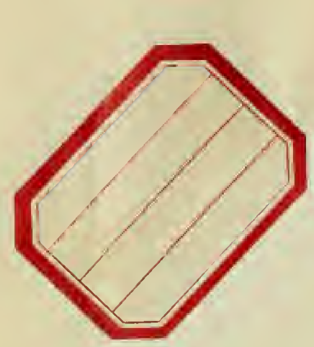


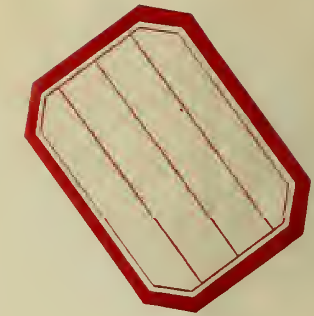
BRAKE STAND AND ENGINE

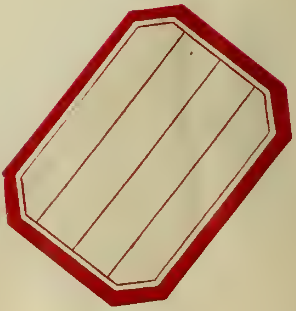
[illegible]



END VIEW OF BRAKE STAND







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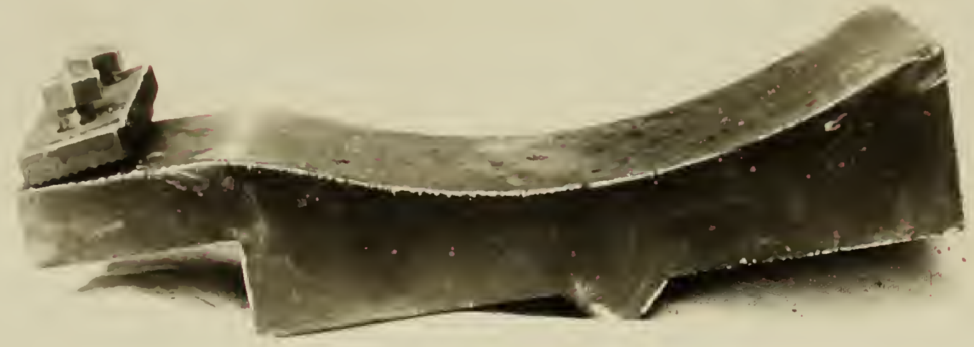

CAST IRON BRAKE SHOE

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